Semiannual water column monitoring report

February – July 1999

Massachusetts Water Resources Authority

Environmental Quality Department
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SEMIANNUAL WATER COLUMN MONITORING REPORT

February – July 1999

Submitted to

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EXECUTIVE SUMMARY

The Massachusetts Water Resources Authority (MWRA) has collected water quality data in Massachusetts and Cape Cod Bays for the Harbor and Outfall Monitoring (HOM) Program since 1992. This monitoring is in support of the HOM Program mission to assess the potential environmental effects of the relocation of effluent discharge from Boston Harbor to Massachusetts Bay. The data are being collected to establish baseline water quality conditions and ultimately to provide the means to detect significant departure from that baseline. The surveys have been designed to evaluate water quality on both a high-frequency basis for a limited area in the vicinity of the outfall site (nearfield) and a low-frequency basis over an extended area throughout Boston Harbor, Massachusetts Bay, and Cape Cod Bay (farfield). This semi-annual report summarizes water column monitoring results for the nine surveys conducted from February through July 1999.

The winter to spring transition in Massachusetts and Cape Cod Bays is usually characterized by a series of physical, biological, and chemical events: seasonal stratification, the winter/spring phytoplankton bloom, and nutrient depletion. This was generally the case in 1999 with the onset of stratification in April, very high chlorophyll concentrations during the winter/spring period and surface waters depleted in nutrients from May through July.

The first three surveys of 1999 (February through March) were conducted prior to the onset of stratification. The water column was well mixed and relatively high concentrations of nutrients were measured. Nutrient concentrations generally decreased from February to March coincident with increasing chlorophyll concentrations and elevated primary production rates. The high nearfield chlorophyll concentrations observed during the winter of 1998 had remained elevated into the winter/spring period of 1999. Primary production at the nearfield stations was relatively high during this period reaching values of >2000 mg C m^{-2} d^{-1}, which is comparable to winter/spring blooms observed during previous baseline monitoring years. The phytoplankton community was a mixed assemblage dominated by microflagellates and chain forming centric diatoms. The pennate diatom, *Pseudo-nitzschia pungens*, which includes both non-toxic *P. pungens* and domoic-acid-producing *P. multiseries*, was observed throughout Massachusetts Bay in early February.

In April, the onset of stratification was observed at the deeper nearfield, offshore and boundary stations. The shallow Harbor, coastal and Cape Cod Bay stations, however, remained well mixed. In early April, nutrient concentrations at the boundary and northern offshore area stations were relatively high and comparable to the values observed in late February. By mid-April and early May, nutrient concentrations had decreased to low levels in the nearfield and southern offshore area stations. The winter/spring bloom reduced nutrient concentrations in the surface waters from February to April and with the onset of stratification nutrient concentrations in the surface waters were depleted throughout much of the region by late April/early May.

The high chlorophyll concentrations observed throughout the Bays during the first three surveys continued to be present in April and reached maxima during this survey in the nearfield and offshore areas. The mean chlorophyll concentration (5.08 μgL^{-1}) for winter/spring of 1999 was greater than any previous winter/spring mean obtained for the nearfield during the baseline-monitoring period. It also exceeded the chlorophyll threshold value (4.76 μgL^{-1}) that had been calculated as the 95th percentile of the baseline winter/spring distribution for 1992 to 1998. None of the other threshold values that have been developed were exceeded during the first half of 1999.

By June, a strong density gradient was observed throughout the Bays except for Boston Harbor stations, which remained homogeneous due to tidal mixing. The establishment of seasonal stratification led to nutrient depleted conditions in the surface waters and ultimately to an increase in nutrient concentrations in bottom waters due to the seasonal increase in rates of respiration and remineralization of organic

matter. Between the April and June surveys, there was a sharp decline in bottom water DO throughout the Bays of 1-3 mgL^{-1}. The trend of declining bottom water DO concentrations following the establishment of stratification and the cessation of the winter-spring bloom is typical. The large decline that was observed, however, may be an indication that DO utilization may be occurring more rapidly and achieve lower concentration in 1999 compared to previous baseline years.

Total zooplankton abundance increased from February through June when extraordinary numbers of zooplankton were observed in the nearfield and Boston Harbor. An astonishing maximum value of >500 x 10^3 animals m^{-3} in Boston Harbor was the highest zooplankton abundance recorded for the entire 1992-1999 baseline. Zooplankton assemblages during the first half of 1999 were comprised of typical taxa, but levels of *Acartia* spp. were unusually low, possibly due to drought, and contributions of meroplankton such as bivalve and gastropod veligers and polychaete larvae were unusually high.

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1.0 INTRODUCTION

1.1 Program Overview

The Massachusetts Water Resources Authority (MWRA) has implemented a long-term Harbor and Outfall Monitoring (HOM) Program for Massachusetts and Cape Cod Bays. The objective of the HOM Program is to (1) test for compliance with NPDES permit requirements; (2) test whether the impact of the discharge on the environment is within the bounds projected by the SEIS; and (3) test whether change within the system exceeds the Contingency Plan thresholds. A detailed description of the monitoring and its rationale is provided in the Effluent Outfall Monitoring Plan developed for the baseline period and the post discharge monitoring plan (MWRA, 1997a).

To help establish the present water quality conditions with respect to nutrients, water properties, phytoplankton and zooplankton, and water-column respiration and productivity, the MWRA conducts baseline water quality surveys in Massachusetts and Cape Cod Bays. The surveys have been designed to evaluate water quality on both a high-frequency basis for a limited area (nearfield) and a low-frequency basis for an extended area (farfield). The nearfield stations are located in the vicinity of the outfall site (Figure 1-1) and the farfield stations are located throughout Boston Harbor, Massachusetts Bay, and Cape Cod Bay (Figure 1-2). The stations for the farfield surveys have been further separated into regional groupings according to geographic location to simplify regional data comparisons. This semi-annual report summarizes water column monitoring results for the nine surveys conducted from February through July 1999 (Table 1-1).

Table 1-1. Water Quality Surveys for WF991-WN999 February to July 1999

Survey #	Type of Survey	Survey Dates
WF991	Nearfield/Farfield	February 2 – 8
WF992	Nearfield/Farfield	February 23 – 28
WN993	Nearfield	March 20
WF994	Nearfield/Farfield	April 1 – May 6[a]
WN995	Nearfield	April 29[b] & May 5
WN996	Nearfield	May 12
WF997	Nearfield/Farfield	June 14 – 19
WN998	Nearfield	July 7
WN999	Nearfield	July 20

[a] Due to severe weather, the WF994 survey was completed over the course of six days in April and May – nearfield samples were collected April 11th and farfield samples were collected April 1, 6, 11, 26, and May 6.
[b] Productivity samples were collected on April 29 prior to postponement of survey due to weather conditions.

Initial data summaries, along with specific field information, are available in individual survey reports submitted immediately following each survey. In addition, nutrient data reports (including calibration information, sensor and water chemistry data), plankton data reports, and productivity and respiration data reports are each submitted five times annually. Raw data summarized within this or any of the other reports are available from MWRA in hard copy and electronic formats.

1.2 Organization of the Semi-Annual Report

The scope of the semi-annual report is focused primarily towards providing an initial compilation of the water column data collected during the reporting period. Secondarily, integrated physical and biological results are discussed for key water column events and potential areas for expanded discussion in the annual water column report are recommended. The report first provides a summary of the survey and laboratory methods (Section 2). The bulk of the report, as discussed in further detail below, presents results of water column data from the first nine surveys of 1999 (Sections 3-5). Finally, the major findings of the semi-annual period are summarized in Section 6.

Section 3 data are provided in data summary tables. The summary tables include the major numeric results of water column surveys in the semi-annual period by survey. A description of data selection, integration information, and summary statistics are included with that section.

Sections 4 (Results of Water Column Measurements) and 5 (Productivity, Respiration, and Plankton Results) include preliminary interpretation of the data with selected graphic representations of the horizontal and vertical distribution of water column parameters in both the farfield and nearfield. The horizontal distribution of physical parameters is presented through regional contour plots. The vertical distribution of water column parameters is presented using time-series plots of averaged surface and bottom water column parameters and along vertical transects in the survey area (Figure 1-3). The time-series plots utilize average values of the surface water sample (the "A" depth, as described in Section 3), and the bottom water collection depth (the "E" depth). Examining data trends along four farfield transects (Boston-Nearfield, Cohassett, Marshfield and Nearfield-Marshfield), and one nearfield transect, allows three-dimensional analysis of water column conditions during each survey. One offshore transect (Boundary) enables analysis of results in the outer most boundary of the survey area during farfield surveys.

Results of water column physical, nutrient, chlorophyll, and dissolved oxygen data are provided in Section 4. Survey results were organized according to the physical characteristics of the water column during the semi-annual period. The timing of water column vertical stratification, and the physical and biological status of the water column during stratification, significantly effects the temporal response of the water quality parameters, which provide a major focus for assessing effects of the outfall. This report describes the horizontal and vertical characterization of the water column during pre-stratification stage (WF991 – WN993), and then further delineates processes occurring during the early stratification stage (WF994 – WN999). Time-series data are provided for the entire semi-annual period for clarity and context of the data presentation.

Productivity, respiration, and plankton measurements, along with corresponding discussion of chlorophyll and dissolved oxygen results, are provided in Section 5. Discussion of the biological processes and trends during the semi-annual period is included in this section. A summary of the major water column events and unusual features of the semi-annual period is presented in Section 6. References are provided in Section 7.

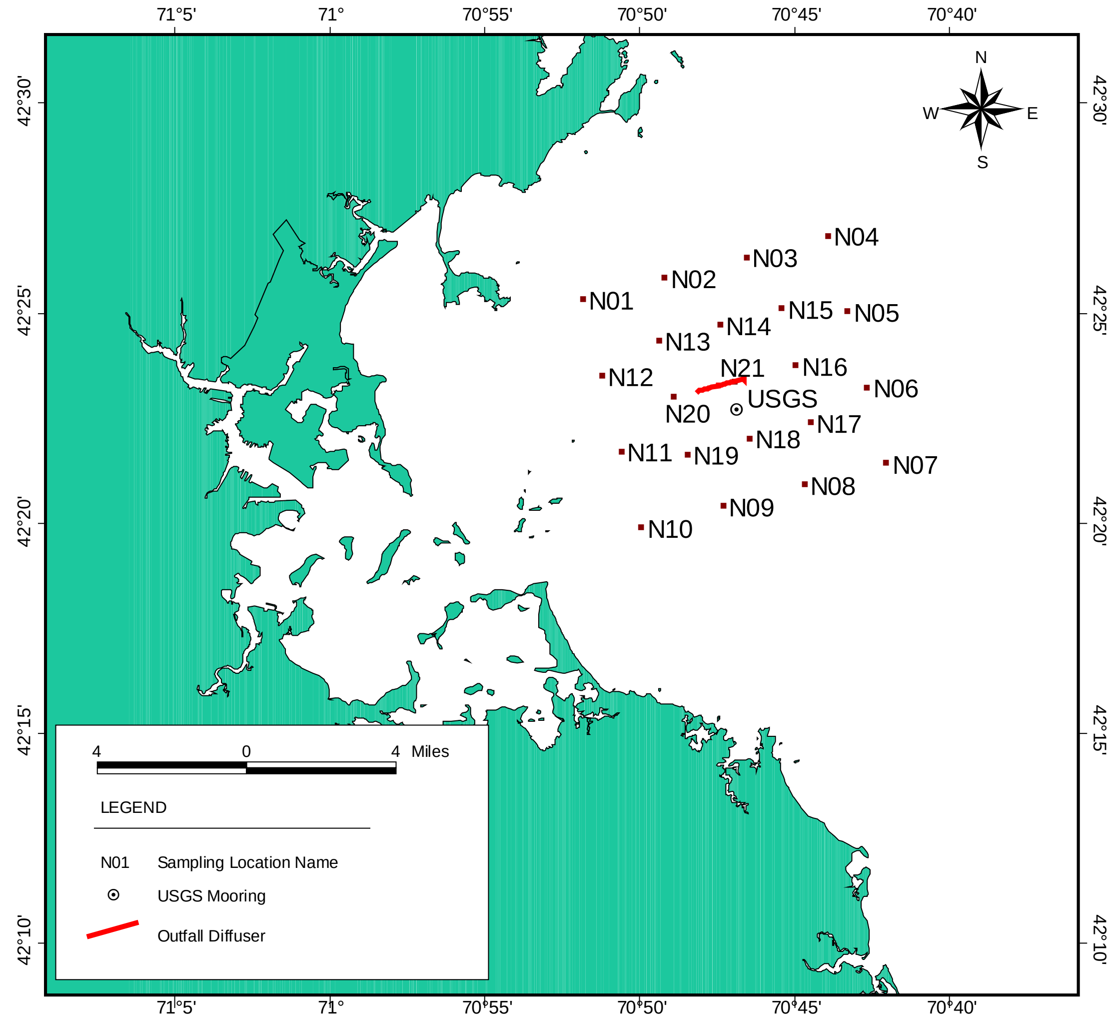


Figure 1-1. Locations of MWRA Offshore Outfall, Nearfield Stations and USGS Mooring

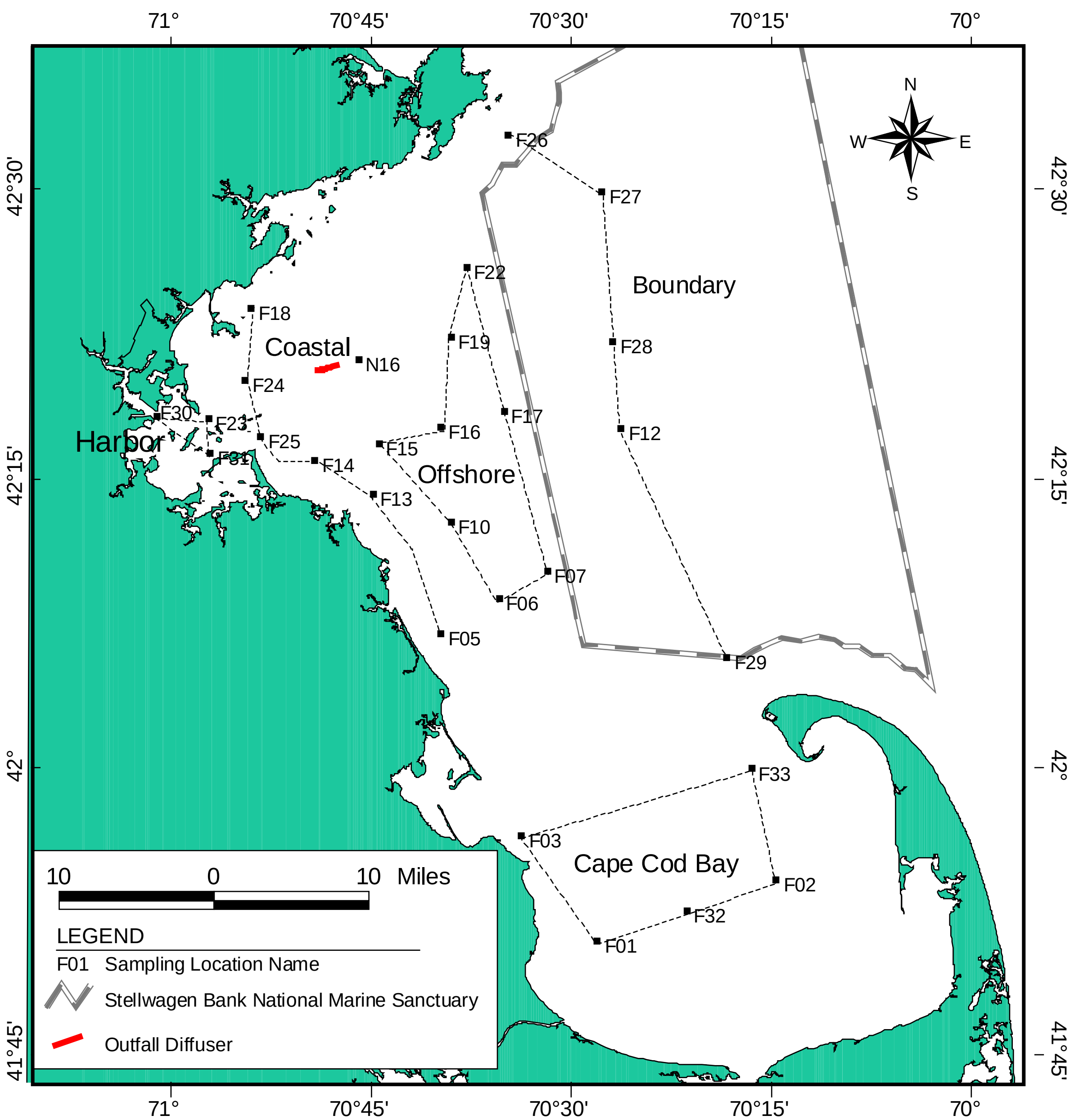


Figure 1-2. Locations of Farfield Stations

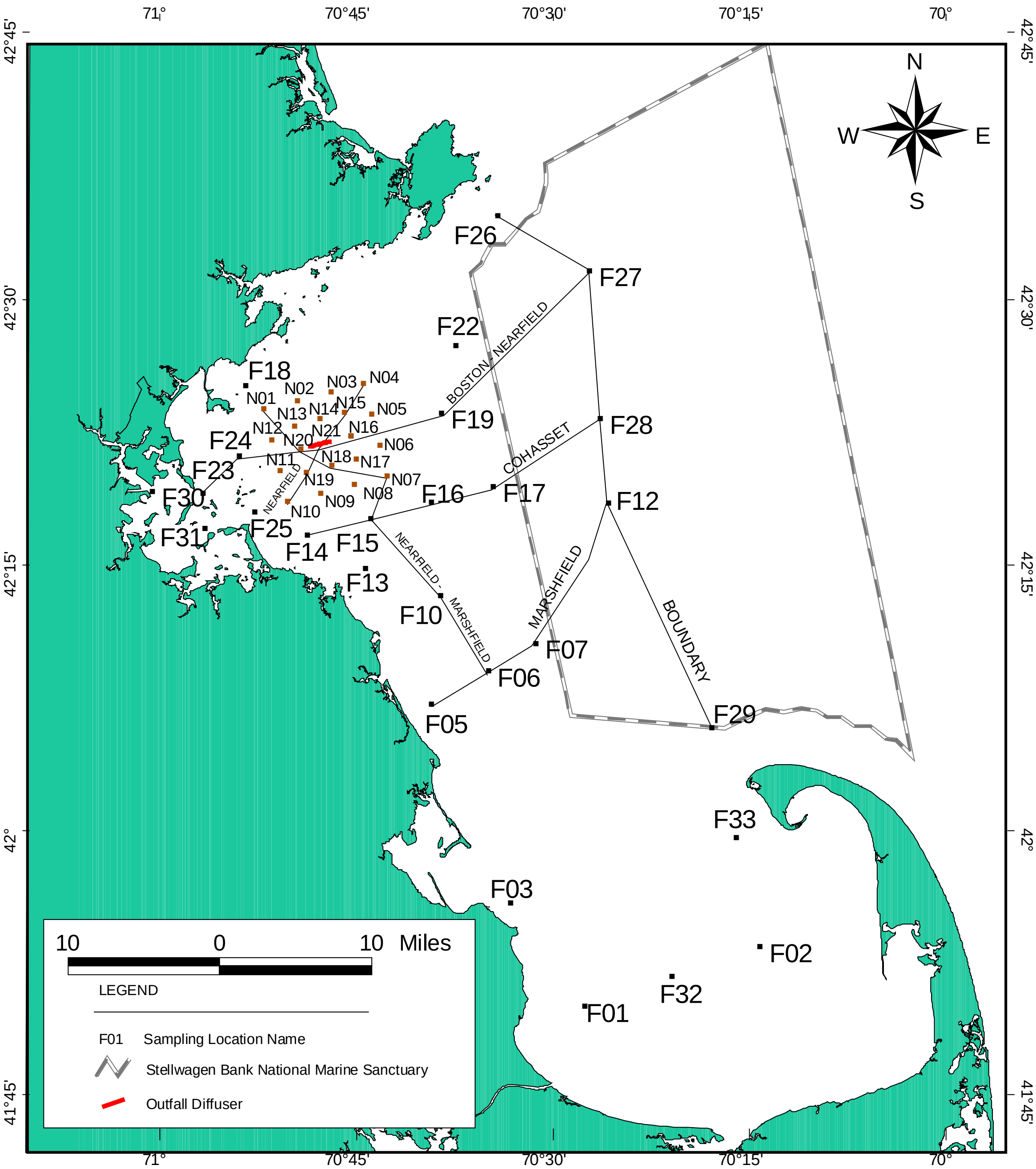


Figure 1-3. Location of Stations Selected for Vertical Transect Graphics Showing Transect Name

2.0 METHODS

This section describes general methods of data collection and sampling for the first nine water column monitoring surveys of 1999. Section 2.1 describes data collection methods, including survey dates, sampling platforms, and analyses performed. Section 2.2 describes the sampling schema undertaken, and Section 2.3 details specific operations for the first 1999 semi-annual period. Specific details of field sampling and analytical procedures, laboratory sample processing and analysis, sample handling and custody, calibration and preventative maintenance, documentation, data evaluation, and data quality procedures are discussed in the Water Quality Monitoring CW/QAPP (Albro *et al*., 1998). Details on productivity sampling procedures and analytical methods are also available in Appendix A.

2.1 Data Collection

The farfield and nearfield water quality surveys for 1999 represent a continuation of the baseline water quality monitoring conducted from 1992 – 1998. The monitoring program has been improved over the years as more data have been collected and evaluated. In 1998, two Cape Cod Bay stations (F32 and F33) were added to better capture the winter/spring variability in zooplankton abundance and species in these Right whale feeding grounds. During the first three farfield surveys of 1999, these two stations were again sampled for zooplankton and hydrographic (CTD) properties.

Water quality data for this report were collected from the sampling platforms *R/V Aquamonitor, F/V Isabel S, and F/V Christopher Andrew.* Continuous vertical profiles of the water column and discrete water samples were collected using a CTD/Go-Flo Bottle Rosette system. This system includes a deck unit to control the system, display *in situ* data, and store the data, and an underwater unit comprised of several environmental sensors, including conductivity, temperature, depth, dissolved oxygen, transmissometry, irradiance, and fluorescence. These measurements were obtained at each station by deploying the CTD; in general, one cast was made at each station. Water column profile data were collected during the downcast, and water samples were collected during the upcast by closing the Go-Flo bottles at selected depths, as discussed below.

Water samples were collected at five depths at each station, except at stations F30, F31, F32, and F33. Stations F30 and F31 are shallow and require only three depths while only zooplankton samples are collected at F32 and F33. These depths were selected during CTD deployment based on positions relative to the pycnocline or subsurface chlorophyll maximum. The bottom depth (within 5 meters of the sea floor) and the surface depth (within 3 meters of the water surface) of each cast remained constant and the mid-bottom, middle and mid-surface depths were selected to represent any variability in the water column. In general, the selected middle depth corresponded with the chlorophyll maximum and or pycnocline. When the chlorophyll maximum occurred significantly below or above the middle depth, the mid-bottom or mid-surface sampling event was substituted with the mid-depth sampling event and the "mid-depth" sample was collected within the maximum. In essence, the "mid-depth" sample in these instances was not collected from the middle depth, but shallower or deeper in the water column in order to capture the chlorophyll maximum layer. These nomenclature semantics result from a combination of field logistics and scientific relevance. In the field, the switching of the "mid-depth" sample with the mid-surface or mid-bottom was transparent to everyone except the NAVSAM operator who observed the subsurface chlorophyll structure and marked the events. The samples were processed in a consistent manner and a more comprehensive set of analyses were conducted for the surface, mid-depth/chlorophyll maximum, and bottom samples.

Samples from each depth at each station were collected by subsampling from the Go-Flo bottles into the appropriate sample container. Analyses performed on the water samples are summarized in

Table 2-1. Samples for dissolved inorganic nutrients (DIN), dissolved organic carbon (DOC), total dissolved nitrogen (TDN) and phosphorus (TDP), particulate organic carbon (POC) and nitrogen (PON), biogenic silica, particulate phosphorus (PP), chlorophyll *a* and phaeopigments, total suspended solids (TSS), urea, and phytoplankton (screened and rapid assessment) were filtered and preserved immediately after obtaining water from the appropriate Go-Flo bottles. Whole water phytoplankton samples (unfiltered) were obtained directly from the Go-Flo bottles and immediately preserved. Zooplankton samples were obtained by deploying a zooplankton net overboard and making an oblique tow of the upper two-thirds of the water column but with a maximum tow depth of 30 meters. Productivity samples were collected from the Go-Flo bottles, stored on ice and transferred to University of Rhode Island (URI) employees. Incubation was started no more that six hours after initial water collection at URI's laboratory. Respiration samples were collected from the Go-Flo bottles at four stations (F19, F23, N04, and N18). Incubations of the dark bottles were started within 30 minutes of sample collection. The dark bottle samples were maintained at a temperature within 2°C of the collection temperature for five to seven days until analysis.

2.2 Sampling Schema

A synopsis of the sampling schema for the analyses described above is outlined in Tables 2-1, 2-2, and 2-3. Station designations were assigned according to the type of analyses performed at that station (see Table 2-1). Productivity and respiration analyses were also conducted at certain stations and represented by the letters P and R, respectively. Table 2-1 lists the different analyses performed at each station. Tables 2-2 (nearfield stations) and 2-3 (farfield stations) provide the station name and type, and show the analyses performed at each depth. Station N16 is considered both a nearfield station (where it is designated as type A) and a farfield station (where it is designated a type D). Stations F32 and F33 are occupied during the first three farfield surveys of each year and collect zooplankton samples and hydrocast data only (designated as type Z).

Table 2-1. Station Types and Numbers (Five Depths Collected Unless Otherwise Noted)

Station Type	**A**	**D**	**E**	**F**	**G[1]**	**P**	**R**	**Z**
Number of Stations	**5**	**8**	**26**	**3**	**2**	**3**	**4**	**2**
Analysis Type								
Dissolved inorganic nutrients (NH_4, NO_3, NO_2, PO_4, and SiO_4)	•	•	•	•	•	•		
Other nutrients (DOC, TDN, TDP, PC, PN, PP, Biogenic Si)[1]	•	•			•	•		
Chlorophyll [1]	•	•			•	•		
Total suspended solids [1]	•	•			•	•		
Dissolved oxygen	•	•		•	•	•		
Phytoplankton, urea [2]		•			•	•		
Zooplankton[3]		•			•	•		•
Respiration [1]						•	•	
Productivity, DIN						•		

[1]Samples collected at three depths (bottom, mid-depth, and surface)
[2]Samples collected at two depths (mid-depth and surface)
[3]Samples collected at the surface

2.3 Operations Summary

Changes in the 1999 sampling schema from prior monitoring years included the addition of the two new zooplankton stations started in 1998 in Cape Cod Bay. The stations were sampled during the first three farfield surveys (WF991, WF992, and WF994). Field operations for water column sampling and analysis during the first semi-annual period were conducted as described above. Deviations from the CW/QAPP for nearfield surveys WN993, WN996, and WF997 had no effect on the data. Principal deviations for surveys WF991, WF992, WF994, WN995, WN998, and WN999 are described below. For additional information about a specific survey, the individual survey reports may be consulted.

During the farfield/nearfield survey in early February (WF991), the respiration samples were allowed to rise to 20° C over a two-day period after being returned to the laboratory. The temperature was corrected upon discovery and the incubation finished. Date are qualified as suspect.

Mid-surface water was not collected at stations F01 and F25 during farfield/nearfield survey WF992 due to Go-Flo bottle problems brought on by the freezing weather.

Due to weather and electronic equipment problems, it took 36 days to complete the farfield/nearfield survey in April (WF994). The Nearfield samples were collected on two separate days (April 7th and April 11th). Productivity samples were collected and analyzed from the April 7th cruise but were not re-sampled on April 11th.

Due to weather problems, the nearfield survey WN995 was started April 29th and finished on May 6th. Productivity samples were collected and analyzed from the April 29th cruise. All parameters except productivity were sampled on May 6th.

No primary productivity was collected from the bottom depth at station N18 for the nearfield survey WN998 due to a misfired Go-Flo bottle.

During the WN999 survey in July, the primary productivity samples were filtered through the 102-µm mesh zooplankton net due to the absence of the 300-µm mesh filtration funnel. Additional whole water sample was collected from the chlorophyll maximum depth to be used as a reference for the 102-µm mesh filtered sample.

Table 2-2. Nearfield Water Column Sampling Plan (3 Pages)

Nearfield Water Column Sampling Plan

Station ID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Rapid Analysis Phytoplankton	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	RP	WW	SW	ZO	UR	RE	AP	IC
			Volume (L)			1	0.1	0.1	1	0.6	0.3	0.5	1	1	4	1	4	1	0.1	1	1	1
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N01	30	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N02	40	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N03	44	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	15.5	2	1	1	1	2	2	2	1	2							6	1	1
			2_Mid-Bottom	4.5	1	1						1		1							1	1
N04	50	D+	3_Mid-Depth	22.1	2	2	1	1	2	2	2	2	2			1	1		1	6	1	1
		R+	4_Mid-Surface	4.5	1	1						1		1							1	1
		P	5_Surface	20.6	2	1	1	1	2	2	2	1	2			1	1		1	6	1	1
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N05	55	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N06	52	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	10.5	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
N07	52	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	10.5	2	1	1	1	2	2	2	1	2	3								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N08	35	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																

Nearfield Water Column Sampling Plan

Station ID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Rapid Analysis Phytoplankton	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	RP	WW	SW	ZO	UR	RE	AP	IC
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N09	32	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N10	25	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N11	32	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N12	26	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N13	32	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N14	34	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N15	42	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N16	40	A	3_Mid-Depth	10.2	2	2	2	2	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N17	36	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																

Nearfield Water Column Sampling Plan

Station ID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and Phosphorous	Particulate Organic Carbon and Nitrogen	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Rapid Analysis Phytoplankton	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	RP	WW	SW	ZO	UR	RE	AP	IC
			1_Bottom	15.5	2	1	1	1	2	2	2	1	2							6	1	1
		D+	2_Mid-Bottom	4.5	1	1						1		1							1	1
N18	30	R+	3_Mid-Depth	26.1	3	1	1	1	2	2	2	2	2		1	1	1		1	6	1	2
		P	4_Mid-Surface	4.5	1	1						1		1							1	1
			5_Surface	20.6	2	1	1	1	2	2	2	1	2			1	1		1	6	1	1
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N19	24	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
			1_Bottom	8.5	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N20	32	A	3_Mid-Depth	10	2	2	1	1	2	2	2	2	2	1								
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	8.5	2	1	1	1	2	2	2	1	2	1								
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
N21	34	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1																
				Totals		111	22	22	42	42	42	42	42	33	1	4	4	2	4	36	10	11
Blanks A									1	1	1	1	1									

Table 2-3. Farfield Water Column Sampling Plan (3 Pages)

Farfield Water Column Sampling Plan

Station ID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and	Particulate Organic Carbon	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	UR	RE	AP	IC
			Volume (L)			1	0.1	0.1	1	0.3	0.3	0.5	1	1	0	1	4	1	0.1	1	1	1
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
F01	27	D	3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
F02	33	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F03	17	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F05	18	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
F06	35	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F07	54	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F10	30	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	4	1	1								1								
			2_Mid-Bottom	2	1	1								1								
F12	90	F	3_Mid-Depth	2	1	1								1								
			4_Mid-Surface	2	1	1								1								
			5_Surface	4	1	1								1	1							
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
F13	25	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			

Farfield Water Column Sampling Plan

Station ID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and	Particulate Organic Carbon	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	UR	RE	AP	IC
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F14	20	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F15	39	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F16	60	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F17	78	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F18	24	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	7	2	1														6		
			2_Mid-Bottom	2	1	1								1								
F19	81	F+R	3_Mid-Depth	7	2	1														6		
			4_Mid-Surface	2	1	1								1								
			5_Surface	7	2	1									1					6		
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F22	80	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	18	3	1	1	1	2	2	2	1	2							6	1	1
			2_Mid-Bottom	8.5	1	1						1		1							1	2
F23	25	D+R+P	3_Mid-Depth	24	3	1	1	1	2	2	2	2	2			1	1		1	6	1	1
			4_Mid-Surface	7.5	1	1						1		1							1	1
			5_Surface	23	3	1	1	1	2	2	2	1	2		1	1	1		1	6	1	1
			6_Net Tow															1				
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	3								
			2_Mid-Bottom	2.5	1	1						1		1								
F24	20	D	3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	9.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
F25	15	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								

Farfield Water Column Sampling Plan

Station ID	Depth (m)	Station Type	Depths	Total Volume at Depth (L)	Number of 9-L GoFlos	Dissolved Inorganic Nutrients	Dissolved Organic Carbon	Total Dissolved Nitrogen and	Particulate Organic Carbon	Particulate Phosphorous	Biogenic silica	Chlorophyll a	Total Suspended Solids	Dissolved Oxygen	Secchi Disk Reading	Whole Water Phytoplankton	Screened Water Phytoplankton	Zooplankton	Urea	Respiration	Photosynthesis by carbon-14	Dissolved Inorganic Carbon
			Protocol Code			IN	OC	NP	PC	PP	BS	CH	TS	DO	SE	WW	SW	ZO	UR	RE	AP	IC
			5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F26	56	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	7.9	2	1	1	1	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
F27	108	D	3_Mid-Depth	15	2	2	1	1	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	1	1	1																
			2_Mid-Bottom	1	1	1																
F28	33	E	3_Mid-Depth	1	1	1																
			4_Mid-Surface	1	1	1																
			5_Surface	1	1	1									1							
			1_Bottom	2	1	1								1								
			2_Mid-Bottom	2	1	1								1								
F29	66	F	3_Mid-Depth	2	1	1								1								
			4_Mid-Surface	2	1	1								1								
			5_Surface	2	1	1								1	1							
			1_Bottom	9.9	2	1	1	1	2	2	2	1	2	3								
			3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
F30	15	G	5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
			1_Bottom	9.9	2	1	1	1	2	2	2	1	2	3								
			3_Mid-Depth	14	2	1	1	1	2	2	2	2	2	1		1	1		1			
F31	15	G	5_Surface	15	2	1	1	1	2	2	2	1	2	3	1	1	1		1			
			6_Net Tow															1				
F32	30	Z	5_Surface												1							
			6_Net Tow															1				
F33	30	Z	5_Surface												1							
			6_Net Tow															1				
			1_Bottom	8.1	2	1	2	2	2	2	2	1	2	1								
			2_Mid-Bottom	2.5	1	1						1		1								
N16	40	D	3_Mid-Depth	15	2	2	2	2	2	2	2	2	2	1		1	1		1			
			4_Mid-Surface	2.5	1	1						1		1								
			5_Surface	13	2	1	1	1	2	2	2	1	2	1	1	1	1		1			
			6_Net Tow															1				
					otals	132	35	35	66	66	66	62	66	76	28	22	22	13	22	36	5	6
			Blanks B						1	1	1	1	1									
			Blanks C						1	1	1	1	1									
			Blanks D						1	1	1	1	1									

3.0 DATA SUMMARY PRESENTATION

Data from each survey were compiled from the final HOM Program 1999 database and organized to facilitate regional comparisons between surveys, and to allow a quick evaluation of results for evaluating monitoring thresholds (Table 3-1 Method Detection Limits, Survey Data Tables 3-2 through 3-10). Each table provides summary data from one survey. A discussion of which parameters were selected, how the data were grouped and integrated, and the assumptions behind the calculation of statistical values (average, minimum, and maximum), is provided below. Individual data summarized in this report are available from MWRA either in hard copy or electronic format.

The spatial pattern of data summary follows the sample design over major geographic areas of interest in Massachusetts Bay, Cape Cod Bay, and Boston Harbor (Section 3.1). Compilation of data both horizontally by region and vertically over the entire water column was conducted to provide an efficient way of assessing the status of the regions during a particular survey. Maximum and minimum values are provided because of the need to assess extremes of pre-outfall conditions relative to criteria being developed for contingency planning purposes (MWRA, 1997b).

Regional compilations of nutrient and biological water column data were conducted first by averaging individual laboratory replicates, followed by field duplicates, and then by station visit within a survey. Prior to regional compilation of the sensor data, the results were averaged by station visit. Significant figures for average values were selected based on precision of the specific data set. Detailed considerations for individual data sets are provided in the sections below.

3.1 Defined Geographic Areas

The primary partitioning of data is between the nearfield and farfield stations (Figures 1-1 and 1-2). Farfield data were additionally segmented into five geographic areas: stations in Boston Harbor (F23, F30, and F31), coastal stations (F05, F13, F14, F18, F24, F25), offshore stations (F06, F07, F10, F15, F16, F17, F19, and F22), boundary region stations (F12, F26, F27, F28, F29), and Cape Cod Bay stations (F01, F02, and F03; and F32 and F33 as appropriate). These regions are shown in Figure 1-2.

The data summary tables include data derived from all of the station data collected in each region. Average, maximum, and minimum values are reported from the cumulative horizontal and vertical dataset as described for each data type below.

3.2 Sensor Data

Six CTD profile parameters provided in the data summary tables include temperature, salinity, density (σ_t), fluorescence (chlorophyll a), transmissivity, and dissolved oxygen (DO) concentration. Statistical parameters (maximum, minimum, and average) were calculated from the sensor readings collected at five depths through the water column (defined as A-E). These depths were sampled on the upcast of the hydrographic profile. The five depth values, rather than the entire set of profile data, were selected to reduce the statistical weighting of deep-water data at the offshore and boundary stations. Generally, the samples were collected in an even depth-distributed pattern. The mid-depth sample (C) was typically located at the subsurface fluorescence (chlorophyll) peak in the water column, depending on the relative depth of the chlorophyll maximum. Details of the collection, calibration, and processing of CTD data are available in the Water Column Monitoring CW/QAPP (Albro *et al*., 1998), and are summarized in Section 2.

Following standard oceanographic practice, patterns of variability in water density are described using the derived parameter sigma-t ($\sigma_{t,}$), which is calculated by subtracting 1,000 kg/m^3 from the recorded density. During this semi-annual period, density varied from 1021.9 to 1025.9, meaning σ_t varied from 21.9 to 25.9.

Fluorescence data were calibrated using concomitant extracted chlorophyll *a* data from discrete water samples collected at a subset of the stations (see CW/QAPP or Tables 2-1, 2-2, 2-3). The calibrated fluorescence sensor values were used for all discussions of chlorophyll in this report. The concentrations of phaeopigments are included in the summary data tables as part of the nutrient parameters.

In addition to DO concentration, the derived percent saturation was also provided. Percent saturation was calculated prior to averaging station visits from the potential saturation value of the water (a function of the physical properties of the water) and the calibrated DO concentration (see CW/QAPP).

Finally, the derived beam attenuation coefficient from the transmissometer ("transmittance") was provided on the summary tables. Beam attenuation is calculated from the natural logarithm of the ratio of light transmission relative to the initial light incidence, over the transmissometer path length, and is provided in units of m^{-1}.

3.3 Nutrients

Analytical results for dissolved and particulate nutrient concentrations were extracted from the HOM database, and include: ammonia (NH_4), nitrite (NO_2), nitrate + nitrite (NO_3+NO_2), phosphate (PO_4), silicate (SiO_4), biogenic silica (BSI), dissolved and particulate organic carbon (DOC and POC), total dissolved and particulate organic nitrogen (TDN and PON), total dissolved and particulate phosphorous (TDP and PP), and urea. Total suspended solids (TSS) data are provided as a baseline for total particulate matter in the water column. Dissolved inorganic nutrients (NH_4, NO_2, No_3+NO_2, PO_4, and SiO_4) were measured from water samples collected from each of the five (A-E) depths during CTD casts. The dissolved organic and particulate constituents were measured from water samples collected from the surface (A), mid-depth (C), and bottom (E) sampling depths (see Tables 2-1, 2-2, and 2-3 for specific sampling depths and stations).

3.4 Biological Water Column Parameters

Four productivity parameters have been presented in the data summary tables. Areal production, which is determined by integrating the measured productivity over the photic zone, and chlorophyll-specific areal production is included for the productivity stations (F23 representing the Harbor, and N04 and N18, representing the nearfield). Because areal production is already depth-integrated, averages were calculated only among productivity stations for the two regions sampled. The derived parameters α (gC[gChla]$^{-1}$h^{-1}[μEm^{-2}s^{-1}]$^{-1}$) and Pmax (gC[gChla]$^{-1}$h^{-1}) are also included. The productivity parameters are discussed in detail in Appendix A.

Respiration rates were averaged over the respiration stations (the same Harbor and nearfield stations as productivity, and additionally one offshore station [F19]), and over the three water column depths sampled (surface, mid- and bottom). The respiration samples were collected concurrently with the productivity samples. Detailed methods of sample collection, processing, and analysis are available in the CW/QAPP (Albro *et al*., 1998).

3.5 Plankton

Plankton results were extracted from the HOM database and include whole water phytoplankton, screened phytoplankton, and zooplankton. Phytoplankton samples were collected for whole-water and screened measurements during the water column CTD casts at the surface (A) and mid-depth (C) sampling events. As discussed in Section 2.1, when a subsurface chlorophyll maximum is observed, the mid-depth sampling event is associated with this layer. The screened phytoplankton samples were filtered through 20-μm Nitrex mesh to retain and concentrate larger dinoflagellate species. Zooplankton samples were collected by oblique tows using a 102-μm mesh at all plankton stations. Detailed methods of sample collection, processing, and analysis are available in the CW/QAPP (Albro *et al*., 1998).

Final plankton values were derived from each station by first averaging analytical replicates, then averaging station visits. Regional results were summarized for total phytoplankton, total centric diatoms, nuisance algae (*Alexandrium tamarense, Phaeocystis pouchetii,* and *Pseudo-nitzschia pungens*), and total zooplankton (Tables 3-2 through 3-10).

Results for total phytoplankton and centric diatoms reported in Tables 3-1 through 3-10 are restricted to whole water surface samples. Results of the nuisance species *Phaeocystis pouchetii* and *Pseudo-nitzschia pungens* include the maximum of both whole water and screened analyses, at both the surface and mid-depth. Although the size and shape of both taxa might allow them to pass through the Nitex screen, both have colonial forms that in low densities might be overlooked in the whole-water samples. For *Alexandrium tamarense*, only the screened samples were reported.

3.6 Additional Data

Two additional data sources were utilized during interpretation of HOM Program semi-annual water column data. Temperature and chlorophyll a satellite images collected near survey dates were preliminarily interpreted for evidence of surface water events, including intrusions of surface water masses from the Gulf of Maine and upwelling (Appendix I). U.S. Geological Service continuous temperature and salinity data were collected from a mooring located between nearfield stations N21 and N18 (Figure 1-1). Hourly temperature and salinity data from the mid-depth (~20 m below surface) and near-bottom (1 m above bottom) are plotted in Figure 3-1. Chlorophyll a data from the MWRA Wetlab sensor mounted at mid-depth (~20 m below surface) on the nearfield USGS mooring are plotted in Figure 3-2.

Table 3-1. Method Detection Limits

Analysis	MDL
Dissolved ammonia (NH_4)	0.02 µM
Dissolved inorganic nitrate (NO_3)	0.01 µM
Dissolved inorganic nitrite (NO_2)	0.01 µM
Dissolved inorganic phosphorus (PO_4)	0.01 µM
Dissolved inorganic silicate (SIO_4)	0.02 µM
Dissolved organic carbon (DOC)	20 µM
Total dissolved nitrogen (TDN)	1.43 µM
Total dissolved phosphorus (TDP)	0.04 µM
Particulate carbon (POC)	5.27 µM
Particulate nitrogen (PON)	0.75 µM
Particulate phosphorus (PARTP)	0.04 µM
Biogenic silica (BIOSI)	0.32 µM
Urea	0.2 µM
Chlorophyll *a* and phaeophytin (EDL)	0.036 µg L^{-1}
Total suspended solids (TSS)	0.1 mg L^{-1}

Table 3-2. Combined Farfield/Nearfield Survey WF991 (Feb 99) Data Summary

		Farfield								
Region		Boundary			Cape Cod Bay			Coastal		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	3.63	4.97	4.17	2.74	3.31	3.00	2.91	3.43	3.10
Salinity	PSU	32.0	32.8	32.3	30.4	31.7	31.3	30.2	31.7	31.1
Sigma _T		25.4	25.9	25.6	24.2	25.2	24.9	24.1	25.2	24.7
Beam Attenuation	m-1	0.65	1.17	0.82	0.92	1.41	1.10	1.08	2.01	1.57
DO Concentration	mg/L	9.49	11.08	10.30	10.81	11.50	11.08	10.86	11.82	11.18
DO Saturation	PCT	92.1	104.3	97.9	98.8	106.4	101.6	99.1	109.5	102.6
Fluorescence	ug/L	0.41	22.08	6.06	3.03	7.07	5.88	0.02	10.04	4.21
Chlorophyll a	ug/L	1.24	2.61	1.97	0.32	4.51	2.05	0.77	3.79	1.86
Phaeopigment	ug/L	0.51	0.78	0.64	0.22	1.16	0.70	0.48	1.24	0.82
Nutrients										
NH4	uM	0.45	1.63	0.73	0.17	3.16	1.87	0.37	11.68	4.22
NO2	uM	0.14	0.25	0.20	0.05	0.35	0.22	0.26	0.51	0.35
NO2+NO3	uM	3.20	10.26	7.70	0.39	8.81	5.43	6.94	11.77	9.03
PO4	uM	0.86	1.22	1.04	0.65	1.16	0.94	0.82	1.36	1.10
SIO4	uM	2.08	8.62	5.38	1.15	6.98	4.75	3.74	10.68	6.84
BIOSI	uM	2.40	3.30	2.97	2.50	4.60	3.47	0.90	6.00	3.83
DOC	uM	141.9	160.0	152.0	138.7	225.5	171.2	158.7	419.5	241.1
PPO4	uM	0.10	0.11	0.10	0.11	0.26	0.19	0.20	0.40	0.28
POC	uM	13.80	21.80	17.17	21.40	68.50	33.92	18.30	35.50	24.33
PON	uM	2.06	3.04	2.46	2.69	16.40	6.02	2.49	4.88	3.66
TDN	uM	18.1	18.9	18.5	9.9	23.2	16.8	19.9	31.9	26.7
TDP	uM	1.15	1.20	1.18	0.61	1.15	0.90	1.12	1.40	1.24
TSS		1.99	3.00	2.61	1.87	5.78	3.86	2.86	6.12	4.84
Urea	uM	0.10	0.20	0.15	0.10	0.40	0.23	0.10	1.00	0.45
Productivity										
Alpha	ALPHA									
Pmax	mgCm-3h-1									
Areal Production	mgCm-2d-1									
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1									
Respiration	uM/hr									
Plankton										
Total Phytoplankton	E6CELLS/L	0.526	0.540		0.719	1.180		0.455	0.755	
Centric diatoms	E6CELLS/L	0.106	0.130		0.229	0.669		0.049	0.307	
Alexandrium tamarense	CELLS/L	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchetiii	CELLS/L	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	E6CELLS/L	0.130	0.181		0.008	0.077		0.012	0.187	
Total Zooplankton	ind/m3	14190.0	14190.0		10707.9	32332.7		9984.6	22899.6	

ND – Not detected in sample

Table 3-2. Combined Farfield/Nearfield Survey WF991 (Feb 99) Data Summary (continued)

Region		Harbor			Offshore			Nearfield		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	2.64	3.08	2.95	3.43	5.12	4.05	2.91	4.84	3.67
Salinity	PSU	29.4	31.0	30.4	31.0	32.6	31.9	31.4	32.5	31.9
Sigma _T		22.7	24.7	24.1	24.7	25.8	25.3	25.0	25.7	25.3
Beam Attenuation	m-1	1.51	2.54	1.89	0.69	1.31	1.00	0.96	1.56	1.24
DO Concentration	mg/L	10.66	11.32	10.99	9.27	12.00	10.61	9.32	12.05	10.99
DO Saturation	PCT	96.6	103.5	99.9	90.1	112.0	100.2	90.1	112.6	102.8
Fluorescence	ug/L	0.16	0.16	0.16	0.05	5.60	1.97	0.05	8.84	4.56
Chlorophyll a	ug/L	0.45	2.03	1.16	2.34	4.03	3.45	0.66	7.04	3.63
Phaeopigment	ug/L	0.37	1.08	0.66	0.31	0.99	0.77	0.20	1.69	0.91
Nutrients										
NH4	uM	5.86	14.31	9.18	0.49	2.75	1.19	0.24	2.54	0.90
NO2	uM	0.38	0.54	0.46	0.17	0.30	0.23	0.17	0.27	0.21
NO2+NO3	uM	8.89	14.06	10.74	5.31	12.04	8.08	4.10	8.32	5.76
PO4	uM	1.12	1.30	1.20	0.88	1.40	1.07	0.73	1.15	0.85
SIO4	uM	7.88	15.81	10.62	2.90	11.52	5.85	2.19	9.18	4.27
BIOSI	uM	3.20	6.50	4.38	3.70	4.80	4.13	1.50	6.40	4.70
DOC	uM	163.3	325.0	218.2	150.5	399.8	249.5	133.6	393.5	209.2
PPO4	uM	0.24	0.55	0.38	0.18	0.28	0.22	0.08	0.42	0.26
POC	uM	20.30	43.00	29.26	20.30	23.70	21.47	7.66	37.40	26.05
PON	uM	3.06	6.09	4.26	3.35	3.82	3.56	1.22	6.10	4.29
TDN	uM	13.2	41.6	32.8	13.9	17.5	15.7	13.1	32.3	17.2
TDP	uM	1.16	1.47	1.35	0.95	1.07	0.99	0.81	1.19	0.95
TSS		2.37	13.21	6.15	2.93	4.57	3.78	2.19	6.27	3.69
Urea	uM	0.40	0.90	0.62	NA	NA	NA	0.10	0.20	0.15
Productivity										
Alpha	ALPHA	0.03	0.06	0.05				0.02	0.15	0.10
Pmax	mgCm-3h-1	4.66	9.15	7.17				0.24	19.09	11.50
Areal Production	mgCm-2d-1	242.80	242.80	242.80				730.40	1185.20	957.80
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	233.60	233.60	233.60				252.10	348.20	300.15
Respiration	uM/hr	NA	NA	NA				NA	NA	NA
Plankton										
Total Phytoplankton	E6CELLS/L	0.378	0.926		0.372	0.377		0.573	0.720	
Centric diatoms	E6CELLS/L	0.063	0.162		0.084	0.106		0.163	0.364	
Alexandrium tamarense	CELLS/L	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchetiii	CELLS/L	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	E6CELLS/L	0.034	0.076		0.054	0.054		0.029	0.160	
Total Zooplankton	ind/m3	4667.5	18739.6		22631.9	22631.9		19060.6	36813.8	

ND – Not detected in sample

Table 3-3. Combined Farfield/Nearfield Survey WF992 (Feb 99) Data Summary

		Farfield								
Region		Boundary			Cape Cod Bay			Coastal		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	2.45	4.45	3.52	2.37	2.93	2.68	2.08	2.79	2.55
Salinity	PSU	31.2	32.6	32.1	30.6	31.6	31.0	30.8	31.7	31.4
Sigma _T		24.9	25.9	25.5	24.4	25.2	24.7	24.6	25.3	25.0
Beam Attenuation	m-1	0.74	1.25	0.93	1.26	2.81	2.01	1.43	2.73	1.90
DO Concentration	mg/L	9.60	12.16	11.07	11.23	11.78	11.52	11.58	12.82	12.09
DO Saturation	PCT	92.0	110.8	103.3	101.8	107.2	104.5	104.4	116.8	109.6
Fluorescence	ug/L	0.25	10.62	4.01	0.95	5.48	3.13	0.54	16.94	8.27
Chlorophyll a	ug/L	3.04	4.55	3.73	1.39	6.78	3.92	2.51	16.12	6.34
Phaeopigment	ug/L	0.68	1.16	0.94	0.42	2.09	1.23	0.92	3.56	1.56
Nutrients										
NH4	uM	0.22	1.95	0.71	0.29	1.78	0.95	0.09	4.68	1.47
NO2	uM	0.11	0.20	0.16	0.02	0.18	0.10	0.01	0.27	0.11
NO2+NO3	uM	3.18	9.16	6.48	0.12	2.76	1.40	0.07	4.06	1.58
PO4	uM	0.60	1.23	0.89	0.49	0.87	0.65	0.36	0.79	0.57
SIO4	uM	1.45	8.27	5.25	0.54	1.81	0.96	0.99	6.17	2.56
BIOSI	uM	4.00	5.20	4.60	6.30	7.50	6.77	3.10	7.30	5.13
DOC	uM	138.4	197.3	159.7	198.6	554.6	358.7	152.4	362.3	193.4
PPO4	uM	0.17	0.29	0.22	0.20	0.38	0.28	0.34	0.84	0.55
POC	uM	13.50	24.00	18.97	32.80	49.80	39.00	29.80	58.80	40.77
PON	uM	2.51	3.89	3.35	4.56	7.64	6.19	4.64	9.29	6.73
TDN	uM	16.0	61.5	32.2	12.4	16.1	14.6	10.1	23.9	16.1
TDP	uM	0.83	1.26	1.05	0.56	0.84	0.68	0.50	0.96	0.74
TSS	ug L-1	2.07	4.47	3.31	3.20	9.27	5.83	1.97	5.79	4.18
Urea	uM	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.20	0.18
Productivity										
Alpha	ALPHA									
Pmax	mgCm-3h-1									
Areal Production	mgCm-2d-1									
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1									
Respiration	uM/hr									
Plankton										
Total Phytoplankton	E6CELLS/L	0.94	1.29		1.45	1.53		1.07	2.53	
Centric diatoms	E6CELLS/L	0.57	0.94		0.90	1.08		0.69	2.00	
Alexandrium tamarense	CELLS/L	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchetiii	CELLS/L	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	E6CELLS/L	0.009	0.057		0.021	0.094		0.015	0.046	
Total Zooplankton	ind/m3	34354.2	34354.2		12408.9	27458.1		41633.7	67712.0	

ND – Not detected in sample

Table 3-3. Combined Farfield/Nearfield Survey WF992 (Feb 99) Data Summary (continued)

								Nearfield		
Region		Harbor			Offshore					
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	2.08	2.28	2.18	2.62	4.55	3.40	2.13	3.70	2.98
Salinity	PSU	30.1	31.3	30.7	31.4	32.6	32.0	30.9	32.2	31.8
Sigma _T		24.1	25.0	24.5	25.0	25.8	25.5	24.7	25.6	25.3
Beam Attenuation	m-1	1.96	7.13	4.66	0.76	1.59	1.09	1.04	3.22	1.67
DO Concentration	mg/L	11.54	11.72	11.62	8.94	12.32	11.20	10.38	12.09	11.59
DO Saturation	PCT	103.3	105.1	103.9	85.7	113.1	104.1	97.4	111.5	106.5
Fluorescence	ug/L	0.07	5.84	2.82	0.18	12.92	4.16	0.01	10.29	6.17
Chlorophyll a	ug/L	1.75	8.43	4.13	2.71	4.25	3.67	1.22	8.49	5.06
Phaeopigment	ug/L	0.71	7.07	2.92	0.63	0.91	0.80	0.38	3.48	1.35
Nutrients										
NH4	uM	3.79	20.02	8.97	0.25	3.96	1.05	0.25	5.64	0.73
NO2	uM	0.01	0.31	0.13	0.05	0.21	0.13	0.06	0.22	0.14
NO2+NO3	uM	0.86	5.08	2.51	0.63	9.17	4.12	0.95	7.07	3.75
PO4	uM	0.57	1.12	0.81	0.47	1.32	0.81	0.48	1.10	0.74
SIO4	uM	1.80	6.32	3.49	0.71	9.17	2.92	1.75	6.40	3.65
BIOSI	uM	4.40	19.30	10.23	2.70	3.10	2.90	4.30	10.10	6.76
DOC	uM	153.3	660.4	258.6	155.4	216.0	176.3	131.6	262.5	176.3
PPO4	uM	0.51	1.48	0.87	0.14	0.51	0.27	0.13	0.59	0.32
POC	uM	29.30	92.50	50.27	21.90	24.80	23.07	22.20	49.40	36.74
PON	uM	4.90	12.36	7.54	3.78	4.51	4.14	3.87	8.36	6.19
TDN	uM	14.5	40.8	26.7	12.4	15.7	14.6	12.1	25.0	16.3
TDP	uM	0.72	1.42	1.01	0.81	0.88	0.84	0.70	1.06	0.84
TSS	ug L-1	5.22	23.59	10.72	1.85	4.87	3.26	2.65	10.73	5.19
Urea	uM	0.20	0.30	0.23	0.10	0.30	0.20	0.10	0.30	0.20
Productivity										
Alpha	ALPHA	0.15	0.19	0.17				0.13	0.31	0.22
Pmax	mgCm-3h-1	18.59	23.10	21.03				13.43	33.11	24.63
Areal Production	mgCm-2d-1	783.30	783.30	783.30				1523.60	2148.60	1836.10
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	240.10	240.10	240.10				483.50	497.30	490.40
Respiration	uM/hr	0.10	0.17	0.13	0.04	0.07	0.05	0.07	0.11	0.09
Plankton										
Total Phytoplankton	E6CELLS/L	1.15	1.60		0.57	1.03		1.15	1.69	
Centric diatoms	E6CELLS/L	0.70	1.14		0.36	0.81		0.89	1.27	
Alexandrium tamarense	CELLS/L	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchetiii	CELLS/L	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	E6CELLS/L	0.018	0.032		0.031	0.047		0.021	0.046	
Total Zooplankton	ind/m3	13029.7	21817.4		23395.0	23395.0		214.9	72343.3	

ND – Not detected in sample

Table 3-4. Nearfield Survey WF993 (Mar 99) Data Summary

		Nearfield		
Region				
Parameter	Unit	Min	Max	Avg
In Situ				
Temperature	C	2.55	3.53	2.91
Salinity	PSU	31.4	32.1	31.7
Sigma _T		25.0	25.5	25.2
Beam Attenuation	m-1	0.76	1.12	0.91
DO Concentration	mg/L	10.38	11.91	11.39
DO Saturation	PCT	96.1	110.0	104.4
Fluorescence	ug/L	1.10	9.18	4.90
Chlorophyll a	ug/L	0.34	6.49	2.44
Phaeopigment	ug/L	0.08	0.90	0.44
Nutrients				
NH4	uM	0.18	2.74	0.63
NO2	uM	0.01	0.22	0.16
NO2+NO3	uM	3.93	9.25	6.20
PO4	uM	0.44	1.03	0.72
SIO4	uM	3.60	10.39	6.02
BIOSI	uM	1.90	3.80	2.84
DOC	uM	142.7	406.0	201.5
PPO4	uM	0.09	0.33	0.23
POC	uM	1.40	39.30	21.19
PON	uM	0.27	7.21	3.85
TDN	uM	12.1	31.4	18.5
TDP	uM	0.82	1.34	0.99
TSS	ug L-1	1.02	7.00	3.45
Urea	uM	0.06	0.29	0.20
Productivity				
Alpha	ALPHA	0.021	0.080	0.042
Pmax	mgCm-3h-1	1.38	6.65	4.19
Areal Production	mgCm-2d-1	573.0	1124.1	848.6
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	506.1	536.7	521.4
Respiration	uM/hr	0.02	0.07	0.04
Plankton				
Total Phytoplankton	E6CELLS/L	1.04	1.33	
Centric diatoms	E6CELLS/L	0.75	1.02	
Alexandrium tamarense	CELLS/L	ND	ND	
Phaeocystis pouchetiii	CELLS/L	ND	ND	
Psuedo-nitzschia pungens	E6CELLS/L	0.005	0.010	
Total Zooplankton	ind/m3	30381.0	32547.5	

ND – Not detected in sample

Table 3-5. Combined Farfield/Nearfield Survey WF994 (Apr 99) Data Summary

		Farfield								
Region		Boundary			Cape Cod Bay			Coastal		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	3.14	5.07	3.83	3.76	5.41	4.54	4.99	9.36	7.08
Salinity	PSU	29.6	32.6	31.7	31.1	31.7	31.4	30.2	30.7	30.4
Sigma _T		23.4	25.9	25.2	24.5	25.2	24.9	23.4	24.3	23.8
Beam Attenuation	m-1	0.55	1.43	0.79	1.24	1.70	1.36	0.56	1.83	1.20
DO Concentration	mg/L	10.04	12.97	11.19	11.29	12.07	11.66	9.67	12.84	11.15
DO Saturation	PCT	93.1	123.8	105.1	105.8	114.7	111.1	101.5	124.6	111.8
Fluorescence	ug/L	0.27	7.86	1.78	1.37	10.29	6.34	0.02	11.15	4.55
Chlorophyll a	ug/L	0.66	2.41	1.48	3.59	9.70	6.10	2.05	10.88	5.93
Phaeopigment	ug/L	0.27	0.75	0.42	0.22	1.40	0.74	0.59	1.64	1.09
Nutrients										
NH4	uM	0.06	1.94	0.76	2.54	2.69	2.62	0.14	4.48	1.77
NO2	uM	0.02	0.25	0.16	0.00	0.06	0.02	0.01	0.30	0.10
NO2+NO3	uM	0.30	12.13	7.82	0.01	0.25	0.08	0.02	4.93	1.35
PO4	uM	0.26	1.13	0.87	0.14	0.36	0.24	0.19	0.54	0.38
SIO4	uM	2.60	13.67	8.93	0.29	2.36	0.88	3.22	8.43	5.89
BIOSI	uM	1.80	2.00	1.93	0.70	6.60	4.30	2.00	7.20	4.87
DOC	uM	165.8	382.1	243.6	153.1	416.6	258.7	177.0	380.9	269.1
PPO4	uM	0.06	0.21	0.14	0.28	0.42	0.38	0.23	0.79	0.45
POC	uM	10.10	27.60	18.50	35.00	58.90	46.77	22.60	53.00	39.22
PON	uM	1.91	4.31	3.18	4.77	6.94	6.09	3.86	9.14	6.70
TDN	uM	12.5	19.1	15.5	8.1	17.7	11.1	12.8	38.0	17.8
TDP	uM	0.42	0.85	0.67	0.46	0.93	0.61	0.24	0.98	0.64
TSS	ug L-1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Urea	uM	0.15	0.15	0.15	0.06	0.25	0.15	0.15	3.02	1.32
Productivity										
Alpha	ALPHA									
Pmax	mgCm-3h-1									
Areal Production	mgCm-2d-1									
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1									
Respiration	uM/hr									
Plankton										
Total Phytoplankton	E6CELLS/L	0.57	0.61		1.03	3.42		0.70	2.08	
Centric diatoms	E6CELLS/L	0.03	0.08		0.44	2.71		0.20	1.10	
Alexandrium tamarense	CELLS/L	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchetiii	CELLS/L	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	E6CELLS/L	ND	ND		0.00	0.01		0.00	0.01	
Total Zooplankton	ind/m3	16389.9	16389.9		5473.8	20050.9		11818.3	115340.7	

NA – Not available due to sample loss ND – Not detected in sample

Table 3-5. Combined Farfield/Nearfield Survey WF994 (Apr 99) Data Summary (continued)

Region		Harbor			Offshore			Nearfield		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	5.77	6.60	6.20	3.09	8.85	5.43	3.18	6.94	4.82
Salinity	PSU	28.3	30.5	29.9	30.2	32.5	31.2	30.3	32.1	31.0
Sigma _T		22.2	24.0	23.5	23.4	25.8	24.6	23.8	25.5	24.5
Beam Attenuation	m-1	1.90	2.47	2.15	0.51	1.48	0.83	0.68	2.24	1.35
DO Concentration	mg/L	11.61	12.41	12.05	9.80	12.71	10.84	10.07	13.47	11.96
DO Saturation	PCT	113.4	122.6	118.4	90.6	120.9	105.4	93.5	131.8	114.6
Fluorescence	ug/L	5.81	10.19	7.92	0.32	15.10	4.94	0.25	18.55	7.99
Chlorophyll a	ug/L	1.70	13.37	9.42	0.11	0.89	0.44	0.63	13.75	6.15
Phaeopigment	ug/L	0.45	2.77	1.71	0.13	0.48	0.33	0.22	3.33	1.21
Nutrients										
NH4	uM	0.73	6.99	3.20	0.12	3.78	1.40	0.07	4.70	1.32
NO2	uM	0.00	0.37	0.13	0.01	0.26	0.12	0.00	0.24	0.10
NO2+NO3	uM	0.56	6.02	2.11	0.01	9.75	3.97	0.01	10.58	2.89
PO4	uM	0.18	0.49	0.35	0.17	1.09	0.61	0.13	1.09	0.54
SIO4	uM	1.10	3.72	1.92	3.54	16.01	8.94	0.84	14.73	7.63
BIOSI	uM	7.20	8.80	7.98	0.50	1.20	0.80	0.60	8.00	3.63
DOC	uM	165.7	379.0	269.5	260.7	416.8	338.8	148.8	407.2	272.6
PPO4	uM	0.76	1.02	0.87	0.12	0.16	0.14	0.08	0.80	0.34
POC	uM	44.50	72.20	58.37	12.70	20.20	16.17	12.30	96.70	47.10
PON	uM	6.86	12.14	10.06	2.32	3.97	2.94	2.24	13.43	6.95
TDN	uM	8.2	26.7	15.4	10.0	11.2	10.6	6.1	29.6	14.9
TDP	uM	0.21	0.86	0.54	0.52	0.55	0.54	0.34	1.27	0.75
TSS	ug L-1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Urea	uM	0.06	0.71	0.34	0.01	0.34	0.18	0.15	0.34	0.25
Productivity										
Alpha	ALPHA	0.36	0.53	0.44				0.09	0.22	0.16
Pmax	mgCm-3h-1	43.60	58.20	48.14				4.20	27.90	16.58
Areal Production	mgCm-2d-1	2914.80	2914.80	2914.80				1646.60	2176.30	1911.45
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	251.40	251.40	251.40				328.50	822.30	575.40
Respiration	uM/hr	NA	NA	NA	0.09	0.17	0.13	NA	NA	NA
Plankton										
Total Phytoplankton	E6CELLS/L	1.53	2.99		0.42	0.65		0.83	3.03	
Centric diatoms	E6CELLS/L	0.77	1.80		0.01	0.04		0.06	1.04	
Alexandrium tamarense	CELLS/L	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchetiii	CELLS/L	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	E6CELLS/L	ND	ND		ND	ND		ND	ND	
Total Zooplankton	ind/m3	4075.3	14663.7		195972.4	195972.4		5832.0	112792.5	

NA – Not available due to sample loss ND – Not detected in sample

Table 3-6. Nearfield Survey WF995 (May 99) Data Summary

		Nearfield		
Region				
Parameter	Unit	Min	Max	Avg
In Situ				
Temperature	C	4.08	9.49	7.04
Salinity	PSU	30.2	32.1	30.8
Sigma _T		23.3	25.5	24.1
Beam Attenuation	m-1	0.53	1.64	0.72
DO Concentration	mg/L	8.74	12.41	10.71
DO Saturation	PCT	83.0	123.4	108.1
Fluorescence	ug/L	0.17	8.48	1.15
Chlorophyll a	ug/L	0.08	14.62	1.78
Phaeopigment	ug/L	0.08	2.83	0.70
Nutrients				
NH4	uM	0.26	4.70	1.59
NO2	uM	0.01	0.40	0.15
NO2+NO3	uM	0.02	9.42	2.27
PO4	uM	0.20	1.44	0.56
SIO4	uM	3.80	14.81	9.29
BIOSI	uM	0.50	3.40	1.61
DOC	uM	198.7	406.0	308.6
PPO4	uM	0.12	0.38	0.19
POC	uM	12.40	54.70	21.10
PON	uM	2.28	8.86	3.70
TDN	uM	6.6	20.2	12.5
TDP	uM	0.48	1.17	0.61
TSS		NA	NA	NA
Urea	uM	0.11	0.43	0.21
Productivity				
Alpha	ALPHA	0.012	0.284	0.068
Pmax	mgCm-3h-1	1.14	14.43	5.04
Areal Production	mgCm-2d-1	254.4	736.8	495.6
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	511.1	828.2	669.7
Respiration	uM/hr	0.14	0.76	0.50
Plankton				
Total Phytoplankton	E6CELLS/L	0.33	0.63	
Centric diatoms	E6CELLS/L	0.02	0.05	
Alexandrium tamarense	CELLS/L	ND	ND	
Phaeocystis pouchetiii	CELLS/L	ND	ND	
Psuedo-nitzschia pungens	E6CELLS/L	0.003	0.003	
Total Zooplankton	ind/m3	73693.0	74107.5	

NA – Data not available due to sample loss
ND – Not detected in sample

Table 3-7. Nearfield Survey WN996 (May 99) Data Summary

Region		Nearfield		
Parameter	Unit	Min	Max	Avg
In Situ				
Temperature	C	3.87	12.46	8.35
Salinity	PSU	30.1	32.0	30.9
Sigma _T		22.7	25.4	24.0
Beam Attenuation	m-1	0.54	2.33	0.93
DO Concentration	mg/L	9.18	12.20	10.53
DO Saturation	PCT	86.7	136.7	109.7
Fluorescence	ug/L	0.01	15.65	2.36
Chlorophyll a	ug/L	0.03	13.97	2.95
Phaeopigment	ug/L	0.11	2.04	0.82
Nutrients				
NH4	uM	0.14	4.03	1.13
NO2	uM	0.01	0.29	0.09
NO2+NO3	uM	0.01	8.26	1.58
PO4	uM	0.01	1.12	0.43
SIO4	uM	0.25	13.71	4.51
BIOSI	uM	1.30	5.90	3.20
DOC	uM	159.0	307.2	230.5
PPO4	uM	0.10	0.81	0.31
POC	uM	10.30	96.70	35.41
PON	uM	1.90	9.36	4.68
TDN	uM	5.16	16.11	9.68
TDP	uM	0.24	1.15	0.57
TSS	ug L-1	NA	NA	NA
Urea	uM	0.18	0.60	0.40
Productivity				
Alpha	ALPHA	0.00	0.07	0.04
Pmax	mgCm-3h-1	0.69	5.63	3.59
Areal Production	mgCm-2d-1	813.1	960.8	887.0
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	1114.5	1397.9	1256.2
Respiration	uM/hr	0.18	0.35	0.25
Plankton				
Total Phytoplankton	E6CELLS/L	1.06	1.50	
Centric diatoms	E6CELLS/L	0.37	0.90	
Alexandrium tamarense	CELLS/L	ND	ND	
Phaeocystis pouchetiii	CELLS/L	ND	ND	
Psuedo-nitzschia pungens	E6CELLS/L	ND	ND	
Total Zooplankton	ind/m3	116554.6	123422.5	

NA – Data not available due to sample loss
ND – Not detected in sample

Table 3-8. Combined Farfield/Nearfield Survey WF997 (Jun 99) Data Summary

Region		Farfield								
		Boundary			Cape Cod Bay			Coastal		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	4.24	16.82	9.67	5.24	18.66	11.31	8.38	15.78	13.33
Salinity	PSU	31.2	32.3	31.7	30.9	31.9	31.4	31.2	31.7	31.4
Sigma _T		22.6	25.6	24.3	22.0	25.2	23.8	22.9	24.6	23.5
Beam Attenuation	m-1	0.59	2.80	0.99	0.71	3.08	1.27	0.77	1.63	1.08
DO Concentration	mg/L	8.65	10.89	9.40	7.34	10.15	8.60	8.07	9.23	8.69
DO Saturation	PCT	82.6	115.7	101.2	71.4	107.2	96.1	87.6	110.6	101.0
Fluorescence	ug/L	0.13	10.94	3.60	0.43	11.11	3.99	0.14	9.09	3.53
Chlorophyll a	ug/L	0.13	3.63	1.45	0.66	3.75	2.64	0.90	5.87	2.75
Phaeopigment	ug/L	0.12	1.83	0.83	0.17	1.45	1.01	1.07	2.25	1.69
Nutrients										
NH4	uM	0.33	6.95	2.15	0.36	3.90	1.58	0.21	9.13	2.07
NO2	uM	0.03	0.38	0.19	0.01	0.46	0.13	0.02	0.36	0.16
NO2+NO3	uM	0.04	10.16	3.19	0.02	5.09	1.40	0.08	2.16	0.98
PO4	uM	0.17	1.29	0.64	0.12	1.11	0.52	0.27	0.93	0.58
SIO4	uM	1.00	12.33	4.20	1.22	16.25	6.32	2.67	7.66	5.27
BIOSI	uM	0.10	3.30	1.20	0.60	3.60	1.90	0.90	3.20	2.04
DOC	uM	145.5	196.1	178.7	165.9	236.0	201.3	143.4	263.1	204.7
PARTP	uM	0.09	0.33	0.18	0.15	0.38	0.26	0.19	0.74	0.35
POC	uM	13.92	42.25	25.42	16.08	53.17	33.90	16.58	36.50	27.93
PON	uM	2.09	6.17	4.16	2.69	5.25	3.91	2.98	6.71	5.22
TDN	uM	11.7	23.9	15.9	10.1	19.7	13.8	12.1	28.1	19.5
TDP	uM	0.44	1.39	0.84	0.40	1.29	0.88	0.65	1.30	1.04
TSS		NA	NA	NA	NA	NA	NA	NA	NA	NA
Urea	uM	0.54	0.59	0.57	0.45	0.72	0.58	0.45	0.80	0.57
Productivity										
Alpha	ALPHA									
Pmax	mgCm-3h-1									
Areal Production	mgCm-2d-1									
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1									
Respiration	uM/hr									
Plankton										
Total Phytoplankton	E6CELLS/L	0.35	0.36		0.66	1.28		0.51	1.31	
Centric diatoms	E6CELLS/L	0.003	0.004		0.058	0.518		0.016	0.150	
Alexandrium tamarense	CELLS/L	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchetiii	CELLS/L	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	E6CELLS/L	ND	ND		0.0172	0.0172		0.0021	0.0021	
Total Zooplankton	ind/m3	76692.2	76692.2		124849.8	140174.2		94828.8	368794.0	

NA – Data not available due to sample loss   ND – Not detected in sample

Table 3-8. Combined Farfield/Nearfield Survey WF997 (Jun 99) Data Summary (continued)

Region		Harbor			Offshore			Nearfield		
Parameter	Unit	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
In Situ										
Temperature	C	14.04	16.39	15.12	4.30	16.61	9.75	5.63	17.09	11.22
Salinity	PSU	30.5	31.3	31.1	31.2	32.3	31.7	31.2	32.0	31.6
Sigma _T		22.2	23.3	22.9	22.7	25.6	24.3	22.6	25.2	24.0
Beam Attenuation	m-1	1.34	2.74	2.05	0.58	1.25	0.74	0.56	1.55	0.77
DO Concentration	mg/L	7.97	8.51	8.16	8.21	10.64	9.12	8.14	10.05	9.12
DO Saturation	PCT	95.9	101.1	98.2	79.9	114.1	98.3	87.5	112.8	101.2
Fluorescence	ug/L	4.54	19.95	8.96	0.29	12.55	4.15	0.00	11.96	2.92
Chlorophyll a	ug/L	3.00	17.41	8.64	0.85	2.35	1.54	0.23	3.65	1.66
Phaeopigment	ug/L	1.27	5.15	2.83	0.56	1.70	1.38	0.05	1.95	0.98
Nutrients										
NH4	uM	2.74	13.14	8.67	0.17	6.58	1.39	0.08	5.43	1.18
NO2	uM	0.23	0.46	0.36	0.02	1.23	0.21	0.01	0.45	0.15
NO2+NO3	uM	1.49	3.24	2.30	0.01	10.92	2.52	0.02	3.92	1.05
PO4	uM	0.69	1.14	0.96	0.27	1.25	0.67	0.04	0.93	0.49
SIO4	uM	6.13	8.15	7.15	1.14	13.31	4.34	0.79	9.11	3.81
BIOSI	uM	2.20	5.10	3.81	0.50	1.50	1.00	0.10	2.30	0.84
DOC	uM	151.3	240.5	182.5	172.7	189.2	181.0	118.3	326.7	187.0
PARTP	uM	0.39	1.03	0.70	0.17	0.25	0.20	0.07	0.45	0.18
POC	uM	31.58	74.67	51.62	14.17	24.25	19.72	6.55	32.67	19.42
PON	uM	5.51	12.71	9.42	2.81	4.39	3.42	1.41	5.96	3.71
TDN	uM	10.0	30.2	21.0	10.0	14.8	12.6	7.1	31.8	13.1
TDP	uM	0.42	1.53	1.14	0.84	1.04	0.96	0.42	1.54	0.82
TSS		NA	NA	NA	NA	NA	NA	NA	NA	NA
Urea	uM	0.45	3.88	1.11	0.63	3.18	1.91	0.36	0.54	0.45
Productivity										
Alpha	ALPHA	0.138	0.248	0.202				0.013	0.065	0.035
Pmax	mgCm-3h-1	33.70	68.80	47.14				0.71	5.37	2.75
Areal Production	mgCm-2d-1	2851.0	2851.0	2851.0				544.0	675.0	609.5
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	293.9	293.9	293.9				421.9	431.2	426.6
Respiration	uM/hr	0.13	0.26	0.20	0.03	0.22	0.10	0.03	0.11	0.08
Plankton										
Total Phytoplankton	E6CELLS/L	0.98	1.63		0.28	0.36		0.18	0.78	
Centric diatoms	E6CELLS/L	0.062	0.603		0.009	0.025		0.002	0.021	
Alexandrium tamarense	CELLS/L	ND	ND		ND	ND		ND	ND	
Phaeocystis pouchetiii	CELLS/L	ND	ND		ND	ND		ND	ND	
Psuedo-nitzschia pungens	E6CELLS/L	0.0015	0.0015		ND	ND		ND	ND	
Total Zooplankton	ind/m3	96000.0	518481.0		75100.2	75100.2		120523.9	201240.3	

NA – Data not available due to sample loss ND – Not detected in sample

Table 3-9. Nearfield Survey WF998 (Jul 99) Data Summary

		Nearfield		
Region				
Parameter	Unit	Min	Max	Avg
In Situ				
Temperature	C	5.92	17.84	9.94
Salinity	PSU	30.9	32.0	31.8
Sigma _T		22.4	25.2	24.3
Beam Attenuation	m-1	0.56	2.28	0.89
DO Concentration	mg/L	7.74	11.05	9.12
DO Saturation	PCT	78.4	136.5	98.9
Fluorescence	ug/L	0.19	7.45	1.60
Chlorophyll a	ug/L	0.24	7.23	1.91
Phaeopigment	ug/L	0.39	2.07	1.12
Nutrients				
NH4	uM	0.05	2.70	1.09
NO2	uM	0.01	0.35	0.16
NO2+NO3	uM	0.02	5.97	2.02
PO4	uM	0.24	0.97	0.66
SIO4	uM	1.11	10.19	5.11
BIOSI	uM	0.10	3.70	1.05
DOC	uM	141.6	414.2	199.6
PARTP	uM	0.08	0.82	0.28
POC	uM	9.00	72.10	30.53
PON	uM	1.31	8.86	4.40
TDN	uM	8.4	19.7	11.7
TDP	uM	0.54	1.19	0.84
TSS		NA	NA	NA
Urea	uM	0.36	0.63	0.5075
Productivity				
Alpha	ALPHA	0.006	0.073	0.033
Pmax	mgCm-3h-1	0.54	9.47	3.99
Areal Production	mgCm-2d-1	937.6	1124.7	1031.2
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	434.6	665.3	550.0
Respiration	uM/hr	0.03	0.18	0.08
Plankton				
Total Phytoplankton	E6CELLS/L	0.34	0.95	
Centric diatoms	E6CELLS/L	0.01	0.31	
Alexandrium tamarense	CELLS/L	ND	ND	
Phaeocystis pouchetiii	CELLS/L	ND	ND	
Psuedo-nitzschia pungens	E6CELLS/L	ND	ND	
Total Zooplankton	ind/m3	46007.5	164778.4	

NA – Data not available due to sample loss
ND – Not detected in sample

Table 3-10. Nearfield Survey WN999 (Jul 99) Data Summary

		Nearfield		
Region				
Parameter	Unit	Min	Max	Avg
In Situ				
Temperature	C	6.37	20.09	10.84
Salinity	PSU	31.1	32.0	31.8
Sigma _T		21.9	25.2	24.2
Beam Attenuation	m-1	0.57	2.01	0.93
DO Concentration	mg/L	8.05	13.84	9.38
DO Saturation	PCT	82.5	141.8	102.4
Fluorescence	ug/L	0.02	18.90	2.58
Chlorophyll a	ug/L	0.19	10.02	2.59
Phaeopigment	ug/L	0.14	1.33	0.65
Nutrients				
NH4	uM	0.10	3.05	1.08
NO2	uM	0.01	0.42	0.18
NO2+NO3	uM	0.02	6.19	1.90
PO4	uM	0.13	1.04	0.62
SIO4	uM	0.62	16.31	4.55
BIOSI	uM	0.20	4.40	1.48
DOC	uM	137.7	393.9	254.0
PARTP	uM	0.09	0.90	0.34
POC	uM	7.88	112.00	36.41
PON	uM	1.31	9.57	4.62
TDN	uM	9.5	30.4	15.3
TDP	uM	0.32	1.16	0.79
TSS		NA	NA	NA
Urea	uM	0.16	0.79	0.36
Productivity				
Alpha	ALPHA	0.015	0.073	0.042
Pmax	mgCm-3h-1	0.44	9.39	4.14
Areal Production	mgCm-2d-1	1128.9	1219.1	1174.0
Chlorophyll Specific Areal Production	mgC(mg Chla)-1m-2d-1	697.1	806.6	751.9
Respiration	uM/hr	0.01	0.17	0.07
Plankton				
Total Phytoplankton	E6CELLS/L	0.18	0.81	
Centric diatoms	E6CELLS/L	0.001	0.21	
Alexandrium tamarense	CELLS/L	ND	ND	
Phaeocystis pouchetiii	CELLS/L	ND	ND	
Psuedo-nitzschia pungens	E6CELLS/L	ND	ND	
Total Zooplankton	ind/m3	78846.0	112640.0	

NA – Data not available due to sample loss
ND – Not detected in sample

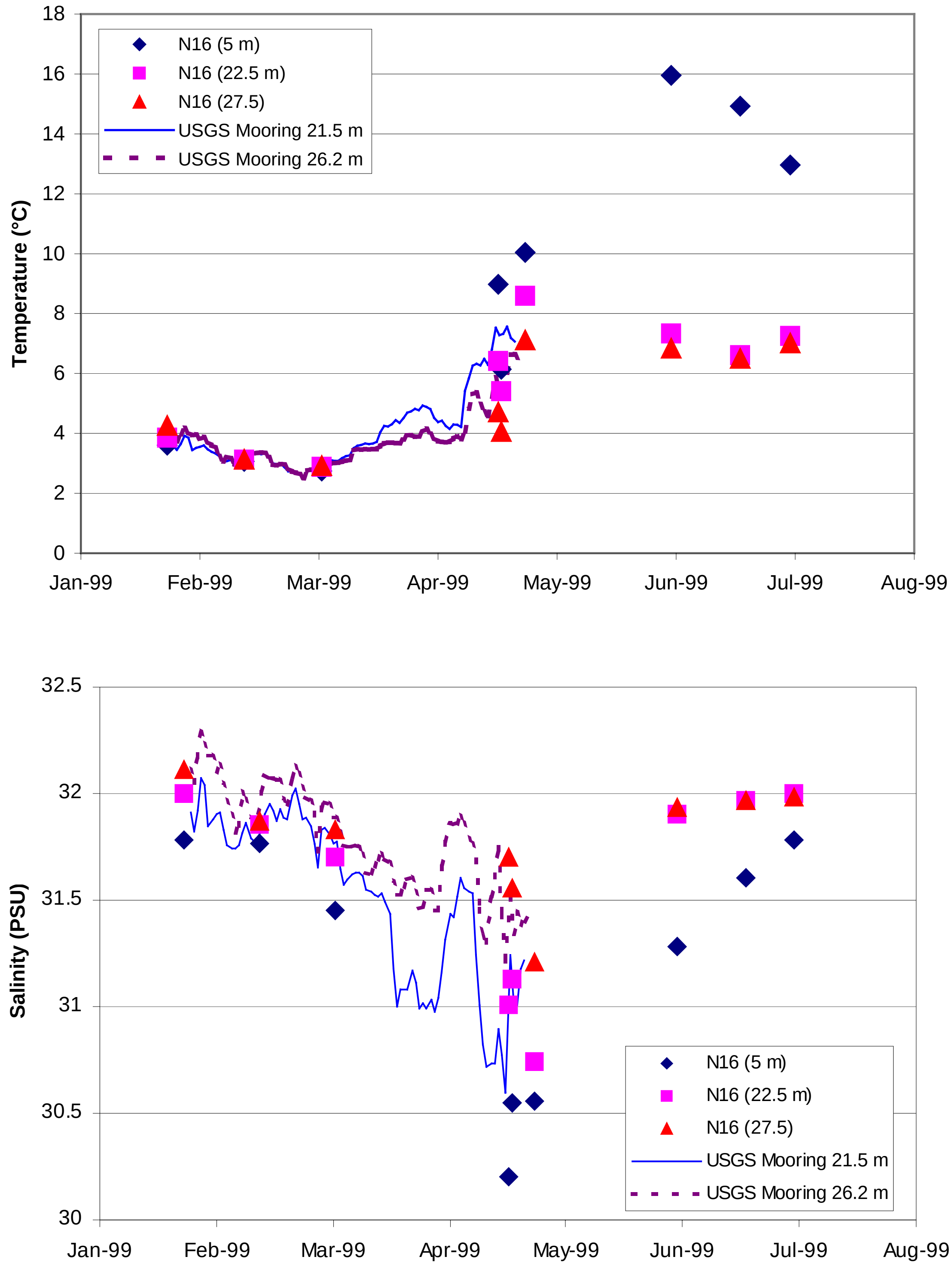


Figure 3-1. USGS Temperature and Salinity Mooring Data from 20 Meters Below Surface and 1 Meter Above Bottom

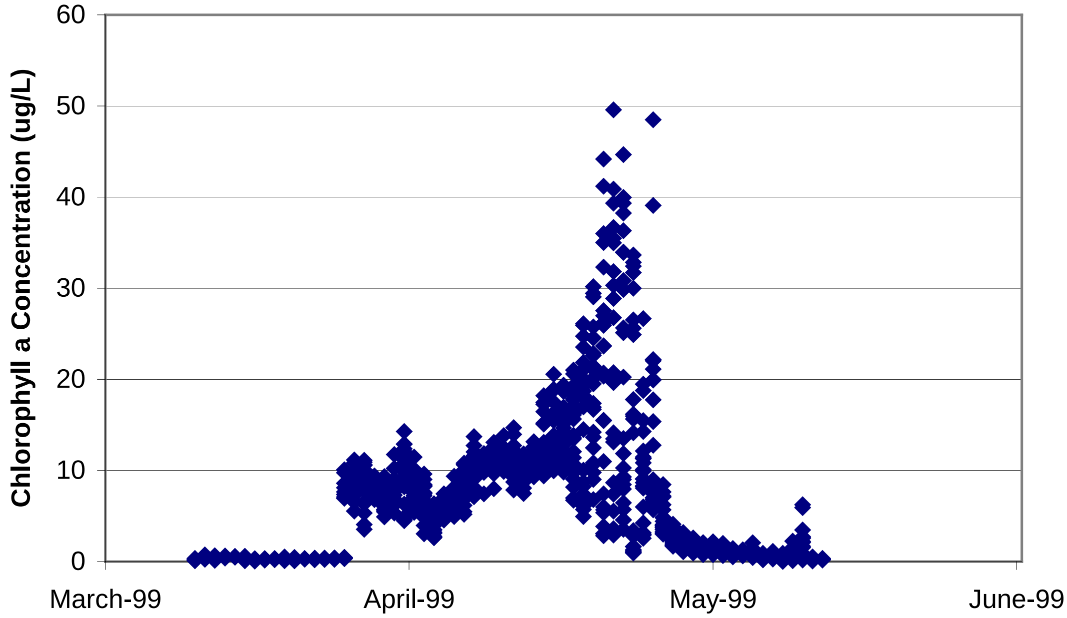


Figure 3-2. MWRA Preliminary Wetlab Chlorophyll a Data (at ~20 m depth)

4.0 RESULTS OF WATER COLUMN MEASUREMENTS

Data presented in this section are organized by type of data and survey. Physical data, including temperature, salinity, density, and beam attenuation are presented in Section 4.1. Nutrients, chlorophyll a, and dissolved oxygen are discussed in Section 4.2. Finally a summary of the major results of water column measurements (excepting biological measurements) is provided in Section 4.3.

Four of the nine surveys conducted during the semi-annual period were combined farfield/nearfield surveys. The first two combined surveys in early and late February (WF991 and WF992) were conducted prior to stratification of the water column. The onset of stratification was observed during the April combined survey (WF994) as shallow Harbor, coastal and Cape Cod Bay stations were still well mixed and the deeper nearfield, offshore and boundary stations were stratified. The last combined survey (WF997) was conducted in June and strong density gradient was observed throughout the Bays except for Boston Harbor stations, which remained well mixed due to tidal flushing. Data collected during the farfield surveys were evaluated for trends in regional water masses throughout the Boston Harbor, Massachusetts Bay and Cape Cod Bay. The variation of regional surface water properties is presented using contour plots of surface water parameters derived from the surface (A) water sample. Classifying data by regions allows comparison of the horizontal distribution of water mass properties over the farfield area.

The April combined survey WF994 took over a month to complete. Data for a majority of the stations, however, were collected between April 1st and April 11th including all data from the Cape Cod Bay, boundary, nearfield and Harbor areas (Figure 1-3). The data collected on April 26th and May 6th were from eight stations (N16F, F05, F06, F07, F10, F13, F14 and F19) in the offshore and coastal areas. The data evaluation presented in this section focuses on the data collected during the first two weeks in April though all data have been included in the representative graphics.

The vertical distribution of water column parameters is presented in the following sections along three farfield transects (Boston-Nearfield, Cohassett and Marshfield) in the survey area and one transect across the Nearfield (Figure 1-3). Examining data trends along transects provides a three-dimensional perspective of water column conditions during each survey. Nearfield surveys were conducted more frequently than farfield surveys allowing better temporal resolution of the changes in water column parameters and the onset of stratification. In addition to the nearfield vertical transect (Figure 1-3), vertical variability in nearfield data is examined and presented by comparing surface and bottom water concentrations (A and E depths) and by plotting individual parameters with depth in the water column. A complete set the surface contour maps, vertical transect plots and parameter scatter plots is provided in Appendices B, C and D, respectively.

4.1 Physical Characteristics

4.1.1 Temperature\Salinity\Density

The timing of the annual setup of vertical stratification in the water column is an important determinant of water quality, primarily because of the trend towards continuously decreasing dissolved oxygen in bottom water in the summer and early fall. The pycnocline, defined as a narrow water depth interval over which density increases rapidly, is caused by a combination of freshwater input during spring runoff and warming of surface water in the summer. Above the pycnocline the surface water is well mixed, and below the pycnocline density increases more gradually. As indicated above, the surface and bottom water density data collected during the combined surveys show that the onset of seasonal stratification had begun in the nearfield and offshore waters by the time of the April survey. For the purposes of this report, the water column is stratified when the difference between surface and bottom water density is greater than 1.0 sigma-t units. Using this definition, the water column was stratified by mid-April (Figure 4-1). The density profiles indicate that the pycnocline was developing across the eastern nearfield by late March (WN993) (Figure 4-2).

4.1.1.1 Horizontal Distribution

In early February (WF991), surface water temperatures were fairly uniform (3.5°C ± 1°C) across the entire farfield/nearfield area. The surface water temperatures ranged from 2.64°C at station F23 in the Harbor to 4.23°C at boundary station F12. In general, there was an inshore to offshore increase in temperatures and colder water in Cape Cod Bay compared to Massachusetts Bay (Figure 4-3). An inshore to offshore increase in surface water salinity was also observed during WF991. Salinity ranged between 29.4 and 32.3 PSU (Figure 4-4). Lower salinity values were observed within the Harbor and at the coastal stations along the south shore. Higher salinity values were found at the offshore and boundary stations. The higher salinity measurements were concomitant with the higher surface temperature along the boundary transect.

Surface water temperatures had cooled slightly by late February (WF982) and continued to be uniform (2.8°C ± 0.8°C) throughout the farfield/nearfield area ranging from 2.08°C at Harbor station F23 to 3.49°C at offshore station F17. The distribution of minimum and maximum surface temperatures followed the general trend of increasing temperatures from the coastal to the offshore waters. A similar pattern was observed for surface salinity data with the lowest surface salinity being observed at Harbor station F30 and the highest at boundary station F28.

By early April (WF984), surface water temperature had increased (5.4°C ± 1.2°C) and there was a decreasing temperature gradient from inshore to offshore (Figure 4-5). In early April, the highest surface temperature was observed at Harbor station F30 (6.60°C) and the lowest at boundary station F28 (4.15°C). By late April and early May, surface temperatures in the coastal and offshore waters had increased 9.0°C ± 0.5°C. Surface salinity values increased from inshore to offshore (Figure 4-6) with the minimum at Harbor station F30 (28.26 PSU) and the maximum at boundary station F28 (31.66 PSU). In early April, lower surface salinity was observed at the stations off of Cape Ann (F26 and F27) and into northern Massachusetts Bay (F22) and is indicative of the spring freshet of lower salinity surface waters from the Gulf of Maine and rivers to the north. Significant amounts of precipitation were measured at Boston's Logan airport from January to late March and flow in the Merrimack River increased over this time period reaching maximum flows in late March and early April (Figure 4-7). The Charles River flow peaked in February and declined thereafter.

The changes that were observed in surface temperatures and salinity from February (WF991 and WF992) to April (WF994) are indicative of the onset of seasonal stratification. By examining the temperature-salinity (T-S) plots, there is a clear change in the relationship between these two parameters between WF991 and WF994 (Figure 4-8). In early February, the trend within each of the regions was that increasing temperatures were concurrent with increasing salinity. The surface waters were generally cooler and less saline than bottom waters and thus the density gradient was not significant. By early April, this trend had reversed and higher temperatures were concomitant with lower salinity. In general, during this survey, surface waters were warmer and less saline. Bottom waters were cooler and more saline. The warmer and more saline waters that were observed in late April and early May at the southern coastal and offshore stations are clearly evident in the T-S plots suggesting that stratification intensified over the course of the month.

During the June farfield/nearfield survey (WF997), surface water temperature across the farfield region varied by 4.5°C (Figure 4-9). The highest temperature was observed in Cape Cod Bay

(18.66°C at station F02) and the lowest temperature was found at boundary station F29 (14.06°C). Surface water temperatures in the nearfield and offshore areas were relatively consistent at 16°C ± 1.0°C. Surface water salinity was also very consistent between all areas with the lowest salinity observed in the Harbor (30.49 PSU at station F30). Outside of the Harbor surface salinity was observed in the range of 31.2 to 31.4 PSU throughout the Bays (Figure 4-10).

The relatively constant surface salinity that was observed in June is consistent with the fact that there was very limited precipitation from late March through late June 1999. National Weather Service data for Boston (Logan Airport) indicate that below normal precipitation was recorded for the area from March through June. These 'drought' conditions in the New England region resulted in relatively high salinity in the coastal waters during this time period. The effect of the drought on salinity in the Harbor and coastal waters and the potential biological ramifications will be evaluated in more detail in the annual water column report.

4.1.1.2 Vertical Distribution

Farfield. The water column was well mixed throughout the region during the winter and early spring of 1999. Generally, there was a decrease in both surface and bottom water density over the course of this period throughout the farfield area (Figure 4-11). The water column was well mixed during each of the areas during the two February surveys. During the April/May survey (WF994), stratified conditions ($\Delta\sigma_t \geq 1.0$) were observed at the boundary and offshore stations. The development of stratification at these stations was primarily driven by a decrease in surface salinity (Figure 4-12), as surface and bottom water temperatures remained relatively unchanged during the first three combined surveys (Figure 4-13). By June (WF997), surface water temperatures had increased by ~10°C throughout the Bays and the offshore, boundary and Cape Cod Bay areas were strongly stratified ($\Delta\sigma_t > 2.0$). At the coastal stations, the water column was less strongly stratified ($\Delta\sigma_t$ ~1.0). The Harbor remained well mixed though June.

The seasonal establishment of stratified conditions was also clearly illustrated in the vertical contour plots of temperature, salinity, and sigma-T for the Boston-Nearfield, Cohassett, and Marshfield transects (Appendix C). In February (WF991), there was little variation in these parameters over the water column, though as shown in the transect plots for σ_t, there was an increase in density from inshore to offshore (Figure 4-14). In April (WF994), the physical characteristics of the water column indicated the onset of seasonal stratification with an increase in the density gradient between the surface and bottom waters (Figure 4-15). By June (WF997), a strong pycnocline had developed throughout the region (Figure 4-16). The onset of stratification in the spring is usually related to a freshening of the surface waters and then as the surface temperatures increase the density gradient or degree of stratification increases. Such was the case in the spring of 1999 as shown in Figure 4-17 the freshening of the surface layer was coincident with the decrease in surface density and the onset of stratification. By June the temperature gradient between surface and bottom waters (Figure 4-18) was clearly driving the density gradient that was observed. A complete set of farfield transect plots of physical water properties is provided in Appendix C.

Nearfield. The onset of stratification can be observed more clearly from the data collected in the nearfield area. The nearfield surveys are conducted on a more frequent basis and thus provide a more detailed picture of the physical characteristics of the water column. As illustrated in Figure 4-19, the water column was well mixed in late February, exhibited a slight density gradient in March (WN993) and had begun to stratify by early April (WF994). By mid-May (WN996) there was a strong density gradient ($\Delta\sigma_t$ ~2) between the surface and bottom waters in the nearfield area. A very strong density gradient ($\Delta\sigma_t > 2$) was observed across the nearfield in June and the nearfield water column remained stratified through the rest of this reporting period (see Figure 4-1). The physical characteristics that led to the establishment of stratified conditions are detailed below.

The gradient between surface and bottom water salinity remained relatively weak (<0.5 PSU) until the early April (Figure 4-20). In April (WF994), surface salinity decreased by ~ 1 PSU across the nearfield and remained ≤ 30.5 PSU through May before returning to ~31.5 PSU in June and July. Meanwhile, bottom salinity remained relatively constant (31.5 – 32.0 PSU) over the entire time period except at the Harbor influenced stations. The decrease in surface salinity in early April resulted from fresh water input to the coastal waters and the freshet from the Gulf of Maine (see Figure 4-6). The resulting salinity gradient that developed initiated the onset of stratification.

The nearfield water column was well mixed with respect to temperature (Figure 4-21) during the first three surveys of 1999. The temperature gradient between surface and bottom waters in the nearfield was also negligible in April when only a 1-2 °C gradient was observed. By early May (WN995), surface water temperature increased to 9 °C while bottom water temperature stayed around 5 °C across the nearfield. At the inner nearfield stations (N10 and N11), surface and bottom water temperatures were similar (~9°C) during WN995 likely because of a combination of storm and tidal mixing. The gradient between surface and bottom waters continued to increase after the establishment of seasonal stratification resulting in a stronger density gradient in May and June. Nearfield surface water temperatures continued to increase reaching a maximum of 17 to 20 °C by late July. The average bottom water temperature remained relatively stable (6-9°C) after establishment of stratified conditions.

4.1.2 Transmissometer Results

Water column beam attenuation was measured along with the other *in situ* measurements at all nearfield and farfield stations. The transmissometer determines beam attenuation by measuring the percent transmission of light over a given path length in the water. The beam attenuation coefficient (m^{-1}) is indicative of particulate concentration in the water column. The two primary sources of particles in coastal waters are biogenic material (plankton or detritus) or suspended sediments. Beam attenuation data is often evaluated in conjunction with fluorescence data to ascertain source of the particulate materials (phytoplankton versus detritus or suspended sediments).

In early February (WF991) surface water beam attenuation ranged from 2.25 m^{-1} at station F30 located in the north Harbor to 0.68 m^{-1} at Boundary station F12 in Stellwagen Basin. There was a decrease from inshore to offshore with elevated values being observed in the Harbor and coastal waters. The gradient decreased across the nearfield and offshore (Figure 4-22). The relatively high beam attenuation values in the nearfield were coincident with elevated chlorophyll concentrations. During the second farfield survey in late February (WF992), surface water beam attenuation in Massachusetts Bay exhibited a sharper decrease in values away from the Harbor (6.11 m^{-1} at F23 to 0.82 m^{-1} at station F12). This evident in the vertical contour of beam attenuation along the Boston-Nearfield transect (Figure 4-23). The high beam attenuation values observed at station F23, coastal stations F18, F24 and F25, and the western nearfield were concomitant with very high surface water fluorescence values. At the boundary stations, the correspondence between beam attenuation (<1.2 m^{-1}) and fluorescence (2.5 to 8.0 $\mu g\ l^{-1}$) was not very strong perhaps due to the lack of the Harbor detrital and suspended sediment signal.

During the April and June farfield/nearfield surveys (WF984 and WF987), beam attenuation in the surface water exhibited a similar decrease in values from inshore to offshore stations and was indicative of an increase in water clarity away from Boston Harbor. In April, the highest surface water beam attenuation values were found at the Harbor stations (2.47 m^{-1} at F23) and values decreased with distance from the Harbor. In June, high surface water beam attenuation values were again observed at the Harbor stations (2.74 m^{-1} at F30) and very low values were found throughout the nearfield and further offshore (0.6 to 0.8 m^{-1}), which was coincident with very low surface water fluorescence.

The clear inshore to offshore horizontal gradient of decreasing beam attenuation away from Boston Harbor can also be seen over the water column along the Boston-Nearfield transect (Figure 4-23). Prior to stratification (WF991 and WF992), elevated beam attenuation values were observed over the entire water column from Harbor station F23 to the middle of the nearfield. Even once seasonal stratification had been established, the influence of the Harbor could be observed over much of the water column at coastal station F24 and into the western nearfield.

4.2 Biological Characteristics

4.2.1 Nutrients

Nutrient data were preliminarily analyzed using x/y plots of nutrient depth distribution, nutrient/nutrient relationships, and nutrient/salinity relationships (Appendix D). As with the physical characteristics, surface water contour maps (Appendix B) and vertical contours from select transects (Appendix C) were also produced from the nutrient data to illustrate the spatial variability of these parameters.

The nutrient data for February to July 1999 represent a return to a more typical progress of seasonal events in the Massachusetts and Cape Cod Bays in comparison to the data collected during the first semiannual period of 1998. Maximum nutrient concentrations were observed in early February when the water column was well mixed and biological uptake of nutrients was limited. The winter/spring 'bloom' reduced nutrient concentrations in the surface waters from February to April. With the onset of stratification, nutrient concentrations in the surface waters were depleted throughout much of the region by late April/early May. Seasonal stratification led to the persistent nutrient depleted conditions in the surface waters and ultimately to an increase in nutrient concentrations in bottom waters due to increased rates of respiration and remineralization of organic matter. The Harbor signal of elevated nutrient concentrations (especially ammonium) was observed throughout this time period.

4.2.1.1 Horizontal Distribution

During this semi-annual period, the highest nutrient concentrations were consistently measured at the Harbor and Harbor influenced coastal and nearfield stations. Dissolved inorganic nutrients were generally at a maximum in surface waters during the first winter survey (WF991). As seen during the fall/winter of 1998 at station F23 near the Deer Island Harbor discharge, ammonium concentrations remained elevated with respect to other stations and compared to previous baseline monitoring years. By late February (WF992), nutrient concentrations had decreased throughout the region with the highest concentrations still observed in the Harbor and lowest in Cape Cod Bay. In April (WF994), unusual patterns in surface nutrient concentrations were observed due to the month long duration of the survey. Interestingly, the pattern when evaluated based on date of sample collection reveals that April was not only a dynamic month weather wise (hence the long survey), but it also was a period of increasing biological production and utilization of nutrients. Nutrient concentrations at the Cape Cod Bay, boundary and northern offshore area stations (April 1st and 6th) were relatively high (excepting Cape Cod Bay stations) and comparable to the values observed in late February. By mid-April and early May, nutrient concentrations had decreased to relatively low levels in the nearfield and southern offshore area stations (except for silicate, which remained elevated). By June (WF997), nutrients had decreased to relatively low concentrations (nitrate at or near detection limits) throughout the region except in Boston Harbor and near Harbor coastal stations.

In early February (WF991), the highest nutrient values were found in or near Boston Harbor (Dissolved inorganic nitrogen (DIN) = 28.37 μM, Nitrate (NO_3) = 13.52 μM and Silicate (SIO_4) = 15.81 μM at station F23; Phosphate (PO_4) = 1.36 μM at coastal station F24). The lowest concentrations were observed in Cape Cod Bay at station F02 (DIN = 0.75 µM; NO_3 = 0.33 µM; SIO_4 = 1.15 µM; PO_4 = 0.65 µM). Nutrient concentrations generally decreased outside of the Harbor and away from the coast as shown for DIN in Figure 4-24. The low nutrient concentrations at station F02 coincided with elevated chlorophyll concentrations and phytoplankton abundance (centric diatoms dominant) and suggest the winter-spring bloom occurred earlier in Cape Cod Bay than Massachusetts Bay, as is the usual pattern. The phytoplankton abundance, though relatively high in comparison to other coincident data, did not achieve abundances that indicate an actual phytoplankton bloom was occurring. The very low concentrations of nitrate and silicate, however, suggest that a bloom event may have occurred prior to this early February survey. Ammonium concentrations in Boston Harbor continued the trend of abnormally high concentrations that had been observed during the fall/winter of 1998.

During the late February survey (WF992), the nutrient pattern was similar to WF991 with high concentrations in the Harbor and along the south shore and decreasing offshore. In general, surface water nutrient concentrations had decreased since early February, but were still replete throughout the region. Ammonium concentrations in the Harbor remained elevated with a maximum concentration at station F30 of 20.02 µM. A very sharp gradient in NH_4 was seen between the Harbor stations and the adjacent coastal stations (Figure 4-25). High chlorophyll concentrations at these Harbor-influenced coastal stations suggest that the strong gradient resulted from biological utilization of NH_4 as it was flushed from the Harbor (see Section 4.2.2.1 for discussion).

In early April (WF994), the spatial pattern persisted with high concentrations in the Harbor, a general decrease in concentrations from inshore to offshore, and lower concentrations in Cape Cod Bay. Due to the month long duration of the survey, however, unusual patterns in surface nutrient concentrations were observed. Nutrient concentrations at the Cape Cod Bay, boundary and northern offshore area stations (sampled on April 1st and 6th) remained relatively high and comparable to the values observed in late February. By mid-April and early May, nutrient concentrations had decreased to relatively low levels in the nearfield and southern offshore area stations (except for silicate, which remained elevated). This pattern was most striking in the NO_3 concentrations, which are presented in Figure 4-26. The low NO_3 (and PO_4) concentrations observed in the nearfield on April 11th were coincident with elevated chlorophyll concentrations and highest production rates observed during this semiannual period. A similar pattern was not observed for SiO_4 due to the dominance of the phytoplankton assemblage by microflagellates and dinoflagellates rather than diatoms. Nutrient concentrations remained low in Cape Cod Bay due to a sustained presence of an abundant phytoplankton assemblage dominated by centric diatoms.

In June (WF997), the highest concentrations were once again found in Boston Harbor (DIN = 13.1, NH_4 = 10.44 µM; NO_3 = 2.25 µM; SIO_4 = 7.51 µM at station F23). Nutrient concentrations outside the Harbor and Harbor influenced coastal stations were very low. The lowest nutrient concentrations were observed at stations in the nearfield (DIN = 0.04 µM, NH_4 = 0.01 µM, and SIO_4 = 1.00 µM at N11; NO_3 = 0.01 µM at N20; PO_4 = 0.10 µM at N05). The low surface water nutrient concentrations found throughout Massachusetts and Cape Cod Bays were coincident with low surface chlorophyll concentrations. This pattern is typical of the stratified, summer conditions that had developed in the Bays by June.

4.2.1.2 Vertical Distribution

Farfield. The vertical distribution of nutrients was evaluated using vertical contours of nutrient data collected along three transects in the farfield: Boston-Nearfield, Cohassett, and Marshfield (Figure 1-3; Appendix C). During the first combined farfield/nearfield survey in early February (WF991), the transect contours indicate that the water column was replete with nutrients. There was an inshore/offshore gradient of decreasing nutrient concentration and little variation over depth for each of the nutrients. This pattern was most pronounced for the NH_4 data that, as expected, clearly showed the Harbor/coastal signal (Figure 4-27). By late February (WF992), nutrient concentrations had decreased in the upper water column, but were still replete along each of the three transects. The inshore/offshore gradients remained more intense than the vertical gradients for each of the nutrients.

By April (WF994), the vertical nutrient distribution had begun to change. There was still a clear inshore/offshore decrease in surface water nutrient concentrations, but NO_3 and PO_4 concentrations had become depleted in the surface waters along both the Boston-Nearfield and Marshfield transects (Figure 4-28). This pattern is deceiving given that the survey was conducted over the course of a month. For instance along the Boston-Nearfield transect stations F27 and F24 were sampled on April 6th, the entire nearfield and station F23 on April 11th and station F19 on April 26th and the three inshore stations along the Marshfield transect were sampled May 6th. Taken in the context of when the stations were sampled, it is clear that NO_3 and PO_4 had become depleted in the surface waters of the nearfield and southern Massachusetts Bay by mid-April to early May. This depletion in nutrients was coincident with elevated chlorophyll concentrations and high rates of primary production and typically occurs following a winter-spring bloom and the onset of stratification (biological uptake and physical barriers to deep-water sources of nutrients).

During the final combined farfield/nearfield survey for this semiannual period, nutrient levels in the surface waters at the non-Harbor-influenced stations were depleted. Ammonium concentrations still exhibited a strong Harbor/coastal signal with a dominant inshore/offshore horizontal gradient of decreasing concentrations. There was a strong vertical gradient for NO_3, PO_4, and SiO_4 along each of the transects with very low concentrations above the pycnocline (~20 m) and replete concentrations below (see Appendix C). A subsurface maximum in chlorophyll was observed at the pycnocline along each of these transects.

Nutrient-salinity plots are useful in distinguishing water mass characteristics and in examining regional linkages between water masses (Appendix D). Dissolved inorganic nitrogen (DIN) plotted as a function of salinity for each of the combined surveys illustrates the transition from winter to summer conditions that was evident for each of the nutrients. During the early February survey, the DIN-salinity plot exhibited a negative correlation between DIN and salinity (Figure 4-29a). This relationship is indicative of winter conditions when the water column is not stratified and the Harbor and coastal waters are a source of low salinity, nutrient rich waters. By late February (WF992), the winter signature was still present with decreasing DIN concentrations with increasing salinity at the Harbor, coastal and western nearfield stations, but there also appears an increase in DIN concentrations at high salinity values (Figure 4-29b). Though stratification had not yet developed, an increase in nutrient uptake in the offshore surface waters led to a small vertical gradient in DIN with lower concentrations in the lower salinity surface waters and higher concentrations at depth. This survey was conducted during the initiation of the transition period between winter and summer biogeochemical conditions. By April, the summer relationship between DIN and salinity was evident in the nearfield data, but due to the length of the survey and the continued influence of elevated concentrations in the Harbor the relationship was obscured (Figure 4-30a). In June (WF997), elevated DIN concentrations were still found at lower salinity in the Harbor and Harbor influenced stations, but the summer conditions in the rest of Massachusetts and Cape Cod Bays was clearly evident (Figure 4-30b). The low DIN concentrations at intermediate salinity represent the surface waters throughout the Bays where biological activity has consumed DIN from both horizontal (Harbor/coastal) and vertical (bottom waters) sources.

Nearfield. In previous sections, the transition from winter to summer physical and nutrient characteristics was discussed. For the nearfield, the transition from winter to summer nutrient regimes can be demonstrated by examining the variations in surface and bottom water NO_3 and SiO_4 concentrations. In Figures 4-31 and 4-32, surface and bottom water NO_3 and SiO_4 concentrations from five nearfield stations representing the four corners (N01, N04, N07, and N10) and the center (N21) of the nearfield were plotted for each of the nine surveys conducted this period. The highest surface water NO_3 concentrations were observed during the first combined survey in February and generally decreased over the course of this period. During the first three surveys (February and March), there was little variation in NO_3 between the surface and bottom waters at each station and the nearfield waters were replete with respect to these nutrients. By April, however, NO_3 concentrations had become depleted and perhaps nutrient limiting in the nearfield surface waters while remaining replete at depth ($\geq$5 µM; Figure 4-31). Nearfield surface waters remained depleted in NO_3 through July.

Surface and bottom water silicate concentrations generally increased from February to early May (Figure 4-32). There was a sharp decrease in surface SiO_4 between the early May (WN995) and mid-May (WN996) surveys from about 5-10 µM to 1-2 µM. This rapid change in SiO_4 concentrations was coincident with an increase in phytoplankton abundance that resulted from a dramatic increase in centric diatoms between the two surveys (see Appendix F). Silicate concentrations remained relatively low in the nearfield surface waters through July.

The relationship of nutrients to salinity in the nearfield followed the trend discussed above for the whole region (see Appendix D). The relationships between nutrients and salinity in the nearfield followed a rather smooth transition from winter to summer condition. In early February, nutrient concentrations decreased with increasing salinity. The nearfield began transitioning between winter and summer nutrient conditions by late February and mid-March. From April through June, nutrients decreased in the surface waters leading to a direct correlation between nutrient concentrations and salinity. In June, DIN concentrations were relatively low over the entire water column and salinity range. By July, nutrient concentrations in the bottom more saline waters had increased due to the remineralization of nutrients from organic matter at depth. The nutrient-salinity plots exhibited the typical summer relationship of increasing nutrient concentrations with increasing salinity (and depth) and the lower salinity surface waters being depleted or nearly depleted of nutrients.

An examination of the nutrient-nutrient plots showed that surface waters were generally depleted in DIN relative to PO_4 and SiO_4 in the nearfield for the entire semi-annual period (Appendix D). The DIN:PO_4 ratio was less than the Redfield value of 16 at all of the nearfield stations for the entire semiannual period. From April through July, the nearfield waters were depleted in DIN versus PO_4 and SiO_4. The data indicate that nutrient limitation due to the lack of NO_3 and NH_4 occurred throughout most of the nearfield from April through July.

4.2.2 Chlorophyll A

Chlorophyll concentrations (based on *in situ* fluorescence measurements) were relatively high during the first three surveys, high throughout the two Bays in April and generally decreased over the remainder of the period although high subsurface maxima were observed through July. The high chlorophyll concentrations in the nearfield during the winter/spring period of 1999 were a continuation of the elevated concentrations observed in late 1998 (Figure 4-33). The mean chlorophyll concentration for the nearfield for winter/spring (February through April) of 1999 was 5.08 μgL^{-1}, which is greater than any previous winter/spring mean obtained for the nearfield during the baseline monitoring period. The 1999 winter/spring mean exceeded the chlorophyll threshold value of 4.76 μgL^{-1} that had been calculated as the 95^{th} percentile of the baseline winter/spring distribution for 1992 to 1998. The elevated chlorophyll concentrations observed during the 1998/1999 winter period will be evaluated in more detail in the annual water column report for 1999.

It is interesting that although the nearfield winter/spring chlorophyll concentrations were unprecedented for the baseline monitoring program phytoplankton abundance was generally lower than previous winter/spring periods. This may have been because the abundant taxa were large cells (*Ceratium* spp.) and chain forming diatoms (*Chaetoceros* spp.) that may not be adequately captured by bottle sampling or had higher per cell chlorophyll values than dominant species in previous years. The high abundance of *Chaetoceros socialis* and *Chaetoceros* chains was also noted by researchers using a video plankton recorder to quantify plankton in the Bays in late February 1999 (Davis and Gallager, 1999). The disconnect between the high chlorophyll concentrations and elevated productivity and relatively low phytoplankton abundance will be a topic of discussion in the 1999 annual water column report.

Maximum chlorophyll values for the Boundary area were observed in early February (WF991). In Cape Cod Bay, elevated values were seen from February to June with the maximum observed in June. Coastal stations also exhibited high chlorophyll maximum values during each of the surveys with the highest levels observed in late February. The nearfield and offshore areas followed similar patterns with relatively high concentrations observed during each survey with maximum and highest survey mean concentrations observed in April. Boston Harbor concentrations increased from low values ($<1.0\ \mu gL^{-1}$) in early February to high values in June ($20\ \mu gL^{-1}$ maximum). The seasonal patterns in chlorophyll that were observed in 1999 are typical for the Bays and Boston Harbor.

4.2.2.1 Horizontal Distribution

Surface chlorophyll concentrations were relatively high throughout the region during the first three combined surveys of 1999 (Figures 4-34, 35 and 36). In early February (WF991), surface chlorophyll values were high in the nearfield ($3\text{-}6\ \mu gL^{-1}$) and Cape Cod Bay ($6\text{-}7\ \mu gL^{-1}$), but the highest value was found at boundary station F27 ($13.46\ \mu gL^{-1}$). Surface chlorophyll concentrations were generally low ($\leq 1\ \mu gL^{-1}$) in Boston Harbor, in coastal waters and in the offshore waters south of the nearfield (Figure 4-34). By late February, surface chlorophyll concentrations in these coastal waters and the western nearfield had increased with the maximum concentration of $15.34\ \mu gL^{-1}$ found at station F18 (Figure 4-35). This increase corresponded with a doubling of phytoplankton abundance, which was primarily due to a large increase in the abundance of centric diatoms (see Section 5.3.1). These elevated surface chlorophyll concentrations were also coincident with a very strong gradient in DIN (primarily NH_4) outside of the Harbor, which was due to the biological drawdown of nitrogenous nutrients in this area. Surface chlorophyll concentrations decreased to the east across the nearfield and offshore and were still relatively low in Boston Harbor and had decreased in Cape Cod Bay.

During the April survey (WF994), surface chlorophyll concentrations were relatively high in Boston Harbor, coastal and nearfield waters. Low concentrations were generally found in the offshore, boundary and Cape Cod areas (Figure 4-36). Microflagellate abundance had increased significantly and had become the dominant phytoplankton in the nearfield by April perhaps accounting for the increase in surface (and subsurface) chlorophyll concentrations. By June (WF997), the phytoplankton assemblage throughout the farfield was dominated by microflagellates and the regional pattern in surface chlorophyll had changed substantially. The chlorophyll concentrations at the Boston Harbor and near-Harbor coastal stations were relatively high ranging from $3\ \mu gL^{-1}$ at station F14 to $20\ \mu gL^{-1}$ at station F30. Surface chlorophyll concentrations decreased sharply further offshore from $1\text{-}2.4\ \mu gL^{-1}$ in the western nearfield to <1 throughout the rest of Massachusetts and Cape Cod Bays. This was coincident with a very strong inshore to offshore decrease in nutrient concentrations and nitrogenous nutrient depletion in the surface waters throughout the Bays. The sharp inshore to offshore decrease in surface chlorophyll concentrations had been observed in the nearfield in mid-May and was also observed during the two July surveys.

4.2.2.2 Vertical Distribution

Farfield. The chlorophyll concentrations over the water column were examined along the three east/west farfield transects (Figure 1-3) to compare the vertical distribution of chlorophyll across the region. In early February (WF991), surface chlorophyll concentrations along the Cohassett and Marshfield transects were relatively low (<1 μgL^{-1}) and increased to 1-3 μgL^{-1} at depths of 5 to 30 m. Along the Boston-Nearfield transect, surface chlorophyll values reached a maximum of 5-7 μgL^{-1} in the western nearfield and coastal waters and decreased inshore to the Harbor and offshore through the nearfield. Higher concentrations of 7-9 μgL^{-1} were found in the subsurface waters of the western nearfield. By late February, surface and subsurface chlorophyll concentrations at coastal station F24 had increased to >13 μgL^{-1} and ranged from 5-11 μgL^{-1} in the western nearfield (Figure 4-37). Subsurface chlorophyll concentrations of 5-9 μgL^{-1} were seen across the nearfield out to Stellwagen Basin (station F19). A subsurface maximum of >13 μgL^{-1} was also observed at station F15 along the Cohassett transect with a subsurface layer (3-7 μgL^{-1}) extending inshore to station F14 and offshore to station F17.

Due to the timing of sampling during the April survey, it is difficult to interpret the vertical transects for this survey as some of the stations along each transect were collected more than a month apart. Therefore, the transects have been evaluated based on segments that were collected concomitantly. In early April, there was a significant bloom in chlorophyll across the nearfield with subsurface concentrations of >13 μgL^{-1} and similar subsurface concentrations were found at station F15 along the Cohassett transect. The nearfield subsurface bloom extended into the coastal and Harbor areas with chlorophyll concentrations of 7-9 μgL^{-1} being observed. Elevated subsurface chlorophyll concentrations of 7-9 μgL^{-1} were also seen extending offshore from station F15 to station F17. Lower concentrations (<5 μgL^{-1}) were seen over the water column along the Marshfield transect to the south, which was sampled the same day (May 6th).

Chlorophyll concentrations had decreased along the transects by the June survey (WF997). The patterns along the transects showed the typical progression to summer conditions with elevated chlorophyll concentrations near sources of nutrients – Boston Harbor and deep bottom waters below the pycnocline (Figure 4-38). Surface chlorophyll concentrations in the Harbor and coastal waters along the Boston-Nearfield transect ranged from 7-9 μgL^{-1}. Subsurface chlorophyll maxima were observed across the nearfield and out to boundary station F27 that was closely associated with the pycnocline at 20 to 30 m (see Figure 4-16). Chlorophyll concentrations in this layer increased from 5-7 μgL^{-1} in the nearfield to 11-13μgL^{-1} at station F19 and >13 μgL^{-1} at station F27. Subsurface maximum chlorophyll layers were also observed along the Cohassett and Marshfield transects. At stations where phytoplankton samples were collected (stations F24, F24, F06, F27 and N16), there was a notable difference in the phytoplankton assemblages associated with the high surface chlorophyll concentrations in the Harbor and coastal areas and the subsurface chlorophyll maximum that was observed along each of the transects. At stations F23 and F24, total phytoplankton abundances were 2 to 3 times higher and diatoms and cryptomonads made up a significant portion of the phytoplankton assemblage. Samples collected from the nearfield, offshore and boundary stations were overwhelmingly dominated by microflagellates during the June survey.

Nearfield. The vertical distribution of chlorophyll was examined along a transect from the southwest corner to the northeast corner of the nearfield area (see Figure 1-3). The southwest corner, station N10, often exhibits a Harbor chlorophyll signal while an offshore chlorophyll signal is more often observed at the northeast corner, station N04. Chlorophyll concentrations were relatively high during the first four surveys of 1999 (Figure 4-39). In early February, surface concentrations ranged from 3-5 μgL^{-1} in the western nearfield to <1 μgL^{-1} in the northeast corner at stations N15 and N04 where subsurface chlorophyll maxima (5-7 μgL^{-1}) were observed. By late February, subsurface chlorophyll concentrations had increased to 7-9 μgL^{-1} across most of the nearfield and remained low (<1 μgL^{-1}) in surface waters in the northeast corner. During the March survey (WN993), surface chlorophyll concentrations were low (<1-3 μgL^{-1}) across most of the nearfield transect and subsurface maxima (5-13 μgL^{-1}) were located deeper in the water column. Phytoplankton data collected from stations N14 and N18 indicate that total abundance and the abundance (and dominance) of centric diatoms increased progressively from early February to March resulting in a concurrent increase in chlorophyll (see Section 5.3.1). The surface and mid-depth phytoplankton abundances were similar in March so it is likely that the elevated chlorophyll concentrations at depth were due to an increase in chlorophyll per cell in response to decreasing light at depth in the well-mixed water column.

The highest chlorophyll concentrations of this semiannual period were observed during the April survey (Figure 4-39). Chlorophyll concentrations in the subsurface maximum layer were >13 μgL^{-1} across most of the nearfield transect. Surface chlorophyll concentrations were high at station N10 (>13 μgL^{-1}) and decreased sharply to <1 μgL^{-1} at station N21 and the eastern nearfield. This was coincident with a very strong inshore to offshore decrease in nutrient concentrations. With the onset of stratification, the winter-spring bloom had depleted nutrients (especially NO_3) in the nearfield surface waters. The availability of nutrients at depth led to the subsurface chlorophyll maximum that was located just above the pycnocline. Phytoplankton abundances in the nearfield chlorophyll maximum samples were almost double that of the surface samples (stations N04, N18 and N16). As would be expected, the elevated chlorophyll concentrations and phytoplankton abundance were concomitant with high production rates during the April survey.

Preliminary chlorophyll data from the MWRA Wetlabs instrument (moored at ~20 m depth near the center of the nearfield area) were comparable (10-13 μgL^{-1}) to the nearfield data that were collected on April 11th. The continuous mooring data indicated that chlorophyll concentrations increased in the nearfield following the survey to 20-50 μgL^{-1} (see Figure 3-2). These data will be reviewed and presented in more detail in the 1999 annual water column report.

By early May, chlorophyll concentrations had decreased to <3 μgL^{-1} over almost all of the nearfield transect (Figure 4-40). There was an equally severe decrease observed in phytoplankton abundance from 2-3 million cells L^{-1} to ~0.5 million cells L^{-1}. Higher chlorophyll concentrations (5-7 μgL^{-1}) were found in the deeper bottom waters at stations N15 and N04, which may have been associated with plankton that had settled out of the water column after the senescence of the bloom. Elevated chlorophyll concentrations were also seen in the surface waters at station N10. By mid-May, the surface chlorophyll concentrations at the Harbor influenced western nearfield stations had increased to 9-11 μgL^{-1} while concentrations remained low further offshore along the transect. By June and into July, the typical summer chlorophyll pattern was observed in the nearfield. Elevated surface chlorophyll concentrations at the Harbor influenced western nearfield stations and subsurface chlorophyll maxima across the rest of the nearfield that are associated with the pycnocline and the nutrients available from the deeper waters.

4.2.3 Dissolved Oxygen

Spatial and temporal trends in the concentration of dissolved oxygen (DO) were evaluated for the entire region (Section 4.2.3.1) and for the nearfield area (Section 4.2.3.2). Due to the relative importance of identifying low DO conditions, bottom water DO minima were examined for the water sampling events. The minimum measured DO concentration was 7.74 mgL^{-1} in the nearfield in July (WN998). Regionally, a DO concentration minimum of 7.34 mgL^{-1} was observed in Cape Cod Bay in June (WF997). DO concentrations were within the range of values observed during previous years though the bottom water concentration in June 1999 was significantly lower than that observed in 1998. Due to the higher concentration of organic matter transferred to the bottom following the winter/spring bloom in 1999, the lower bottom water DO concentrations are not surprising and the trend may continue through the remainder of 1999. The June bottom water DO concentration has traditionally been used as an indicator of DO minimum concentrations in September/October. This early warning indicator could be used to alleviate or at least heighten awareness about potentially harmful bottom water DO conditions that could occur in the fall.

4.2.3.1 Regional Trends of Dissolved Oxygen

The DO of bottom waters was compared between areas and over the course of the four combined surveys. A time series of the average bottom water DO concentration for each area is presented in Figure 4-41a. Average bottom water DO concentrations ranged from 8 to 12 mgL^{-1}. Bottom water DO concentrations remained relatively constant from early February through April. Lower concentrations were consistently observed at the deeper boundary and offshore areas over this period. Between the April and June surveys, there was a sharp decline in bottom water DO throughout the Bays. In Boston Harbor and Cape Cod Bay, bottom water DO concentrations declined by more than 3 mgL^{-1}. Declines of 1.5-2 mgL^{-1} were found in the other areas. The trend of declining bottom water DO concentrations following the establishment of stratification and the cessation of the winter-spring bloom is typical for the Bays. The large decline that was observed, however, may be an indication that DO utilization may be occurring more rapidly and achieve lower concentration in 1999 compared to previous baseline years.

The trend of decreasing DO in the bottom waters was also apparent in the DO %saturation data (Figure 4-41b). In general, DO %saturation increased in each of the areas from early February to April when the highest average DO % saturation was observed. Bottom waters were supersaturated during this time period in the Boston Harbor, Cape Cod Bay and the coastal areas and slightly undersaturated in the deep waters of the boundary and offshore areas. The bottom waters were undersaturated with respect to DO in June in all of the areas with average values ranging from about 85% to 98% saturation.

In February, the spatial distribution of DO generally exhibited an inshore to offshore trend of decreasing DO concentrations along the three regional transects (Appendix C). There was also a decrease in DO with depth. By April, the nearfield bloom led to high DO concentrations in the surface layer and seasonal stratification led to lower DO concentrations in the bottom waters along each of the transects. In June, DO concentrations had decreased throughout the water column and reached relatively low levels (8-9 mgL^{-1}) in the bottom waters (Figure 4-42). Elevated DO concentrations (10-11 mgL^{-1}) were coincident with subsurface chlorophyll maxima along each of the transects (see Figure 4-38).

4.2.3.2 Nearfield Trends of Dissolved Oxygen

Dissolved oxygen concentrations and percent saturation values for both the surface and bottom waters of the 21 nearfield stations were averaged and plotted for each of the nearfield surveys. From February to April, the average surface and bottom water DO concentrations for the nearfield area generally ranged from 10.5-12 mgL^{-1} (Figure 4-43a). A maximum average concentration of 13 mgL^{-1} was observed in the surface waters in April that was coincident with elevated chlorophyll concentrations and high primary production. Following the April survey, DO concentrations decreased in both the surface and bottom waters reaching average concentrations in June and July of about 8 to 9 mgL^{-1}.

There was little variation in average DO %saturation for the surface and bottom waters for the first three surveys of 1999 ranging from 100 to 110 %saturation (Figure 4-43b). With the onset of stratification in April (WF994), the gradient between surface and bottom water DO %saturation began to increase. Surface waters became supersaturated (average >125 %saturation) due to the increased production and phytoplankton and the bottom waters remained unchanged from the previous surveys. Following the April survey, DO %saturation values generally decreased. Although surface waters remained supersaturated, bottom waters decreased to 85 %saturation by July.

In February, the water column was well mixed and DO concentrations were consistent across the nearfield (Figure 4-44). By April, large vertical gradients in DO concentration were observed because of a combination of physical and biological factors. The nearfield water column was becoming stratified separating the biological and chemical processes of the surface and bottom waters. In the surface water, the increase in DO concentrations was concomitant with an increase in chlorophyll concentrations, phytoplankton abundance and production rates. These processes were restricted to the surface water, however and the bottom water DO concentrations remained unchanged. In June and July, the nearfield water column had become strongly stratified. By late July (WN999) DO concentrations remained high in the subsurface chlorophyll maximum layer while in the bottom waters respiration rates had increased and reduced DO concentrations to less than 8 mgL^{-1} in at some stations.

4.3 Summary of Water Column Results

- The onset of stratification was observed during the April combined survey at the boundary and offshore stations. The development of stratification at these stations was primarily driven by a decrease in surface salinity, as surface and bottom water temperatures remained relatively unchanged. By June, surface water temperatures had increased by ~10°C throughout the Bays and a strong density gradient was observed throughout the Bays except for Boston Harbor stations, which remained well mixed due to tidal flushing.
- In the nearfield, the water column had begun to stratify in April and by mid-May there was a strong density gradient between the surface and bottom waters in the nearfield area, which continued to intensify through July.
- The nutrient data for February to July 1999 represented a return to a more typical progress of seasonal events in the Massachusetts and Cape Cod Bays in comparison to the data collected during the first semiannual period of 1998.
  - Maximum nutrient concentrations were observed in early February when the water column was well mixed and biological uptake of nutrients was limited.
  - The winter/spring ‘bloom’ reduced nutrient concentrations in the surface waters from February to April
  - With the onset of stratification in April, nutrient concentrations in the surface waters were depleted throughout much of the region by late April/early May.
  - Seasonal stratification led to persistent nutrient depleted conditions in the surface waters and ultimately to an increase in nutrient concentrations in bottom waters due to increased rates remineralization of organic matter.
- The Harbor signal of elevated nutrient concentrations (especially ammonium) was observed throughout this time period.
- The trend of high chlorophyll concentrations in the nearfield that had been observed in late 1998 continued into the winter/spring period of 1999.
- The mean chlorophyll concentration for the nearfield for winter/spring was higher than any previous winter/spring mean obtained for the nearfield during the baseline monitoring period and exceeded the winter/spring chlorophyll threshold value of 4.76 μgL^{-1}.
- The unprecedented nearfield winter/spring chlorophyll concentrations were not directly reflected in the phytoplankton data. This may have been because the abundant taxa were large cells and chain forming diatoms that may not be adequately captured by bottle sampling or had higher per cell chlorophyll values than dominant species in previous years.
- High chlorophyll concentrations were observed throughout Massachusetts and Cape Cod Bays from February to April and remained relatively high in June. Boston Harbor concentrations increased from low values in early February to high values in June. The seasonal patterns in chlorophyll that were observed in 1999 are typical for the Bays and Boston Harbor.
- DO concentrations in 1999 were within the range of values observed during previous years and followed the typical trends:

- In February, the water column was well mixed and DO concentrations were high and consistent across the region.
  - By April, vertical gradients in DO concentration were observed because the water column was becoming stratified separating the biological and chemical processes of the surface and bottom waters.
  - In the surface waters, increases in chlorophyll concentrations, phytoplankton abundance and production rates led to increased DO concentrations.
  - Due to stratification, these processes were restricted to the surface water and bottom water DO concentrations remained unchanged.
  - In June and July, the nearfield water column had become strongly stratified.
  - DO concentrations remained high in the subsurface chlorophyll maximum layer.
  - In the bottom waters, increased respiration rates reduced DO concentrations to less than 8 mgL^{-1} at some stations.
- The trend of declining bottom water DO concentrations following the establishment of stratification and the cessation of the winter-spring bloom is typical for the Bays. The large decline that was observed, however, may be an indication that DO utilization may be occurring more rapidly and achieve lower concentration in 1999 compared to previous baseline years.

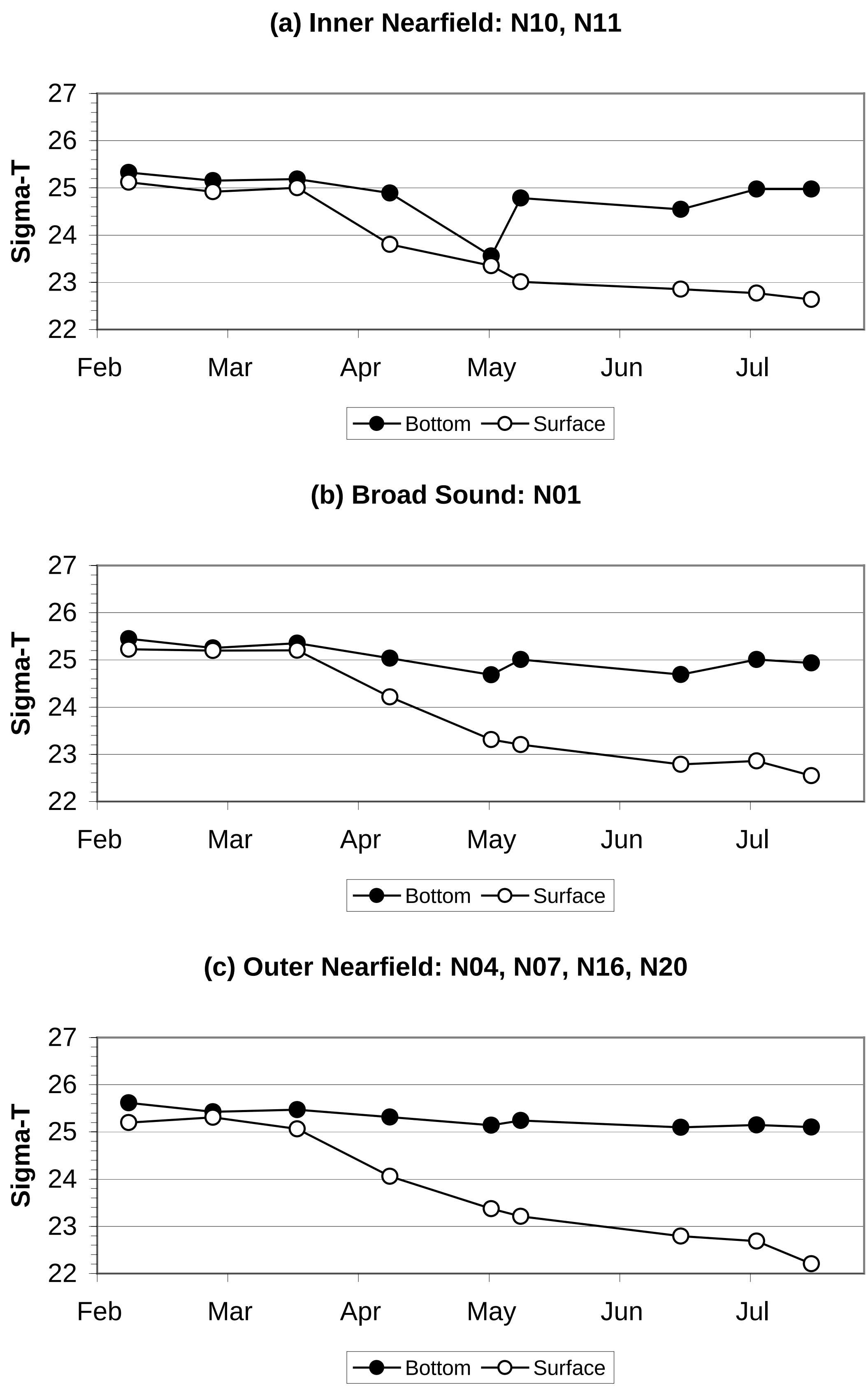


Figure 4-1. Time-Series of Average Surface and Bottom Water Density (σ_t) in the Nearfield

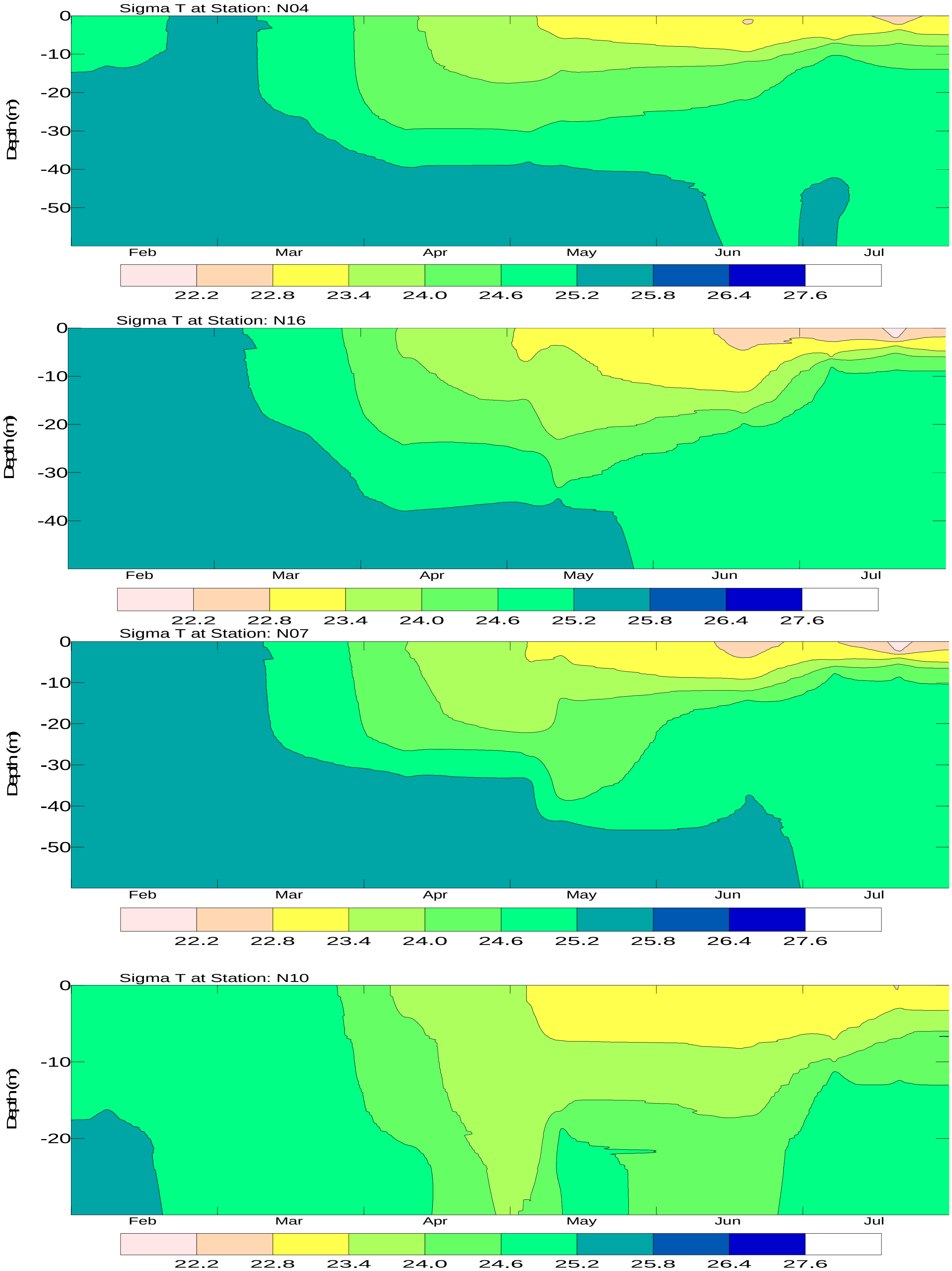


Figure 4-2. Sigma-T Nearfield Depth vs. Time Contour Profiles for Surveys WF991 through WN999

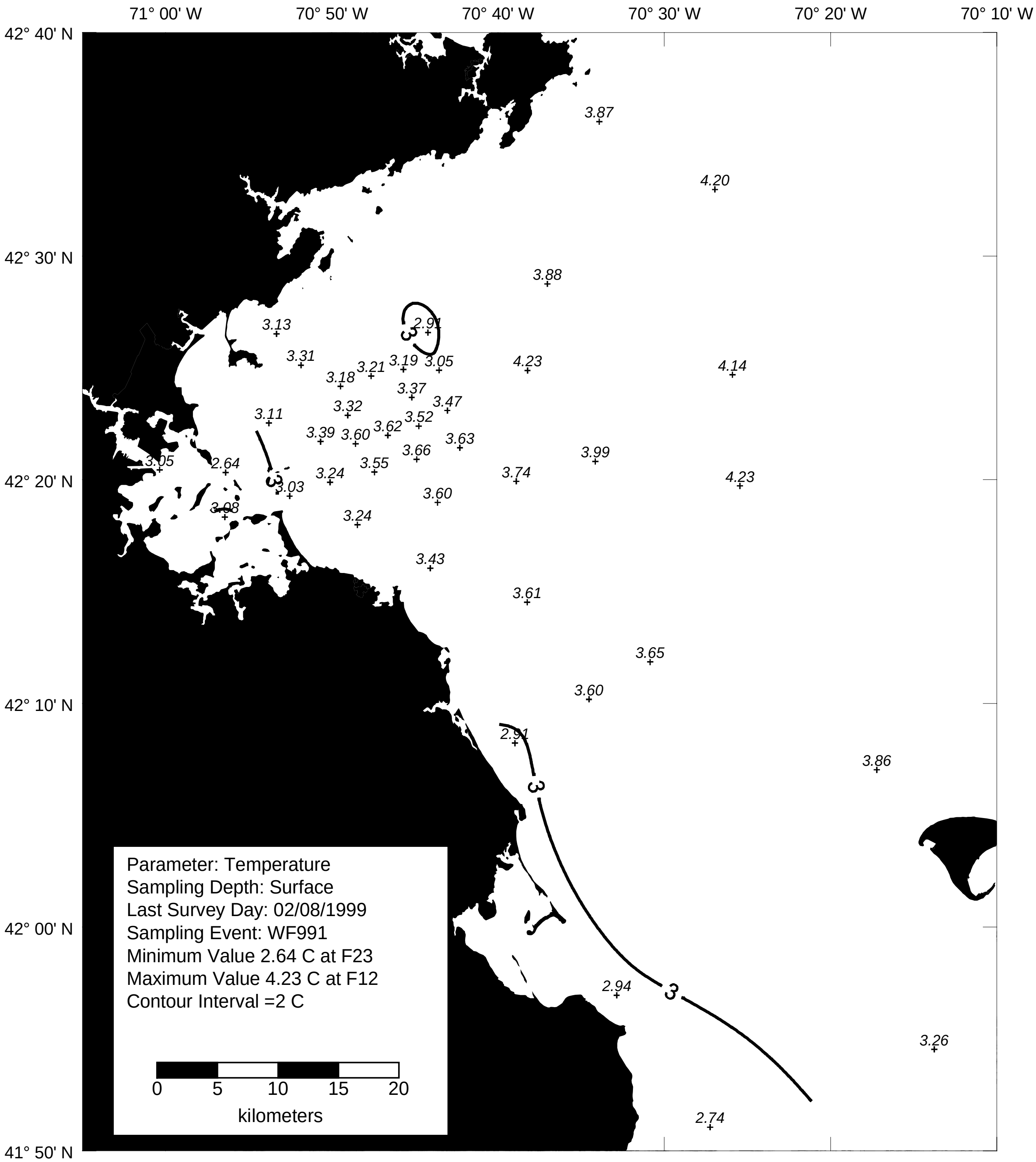


Figure 4-3. Temperature Surface Contour Plot for Farfield Survey WF991 (Feb 99)

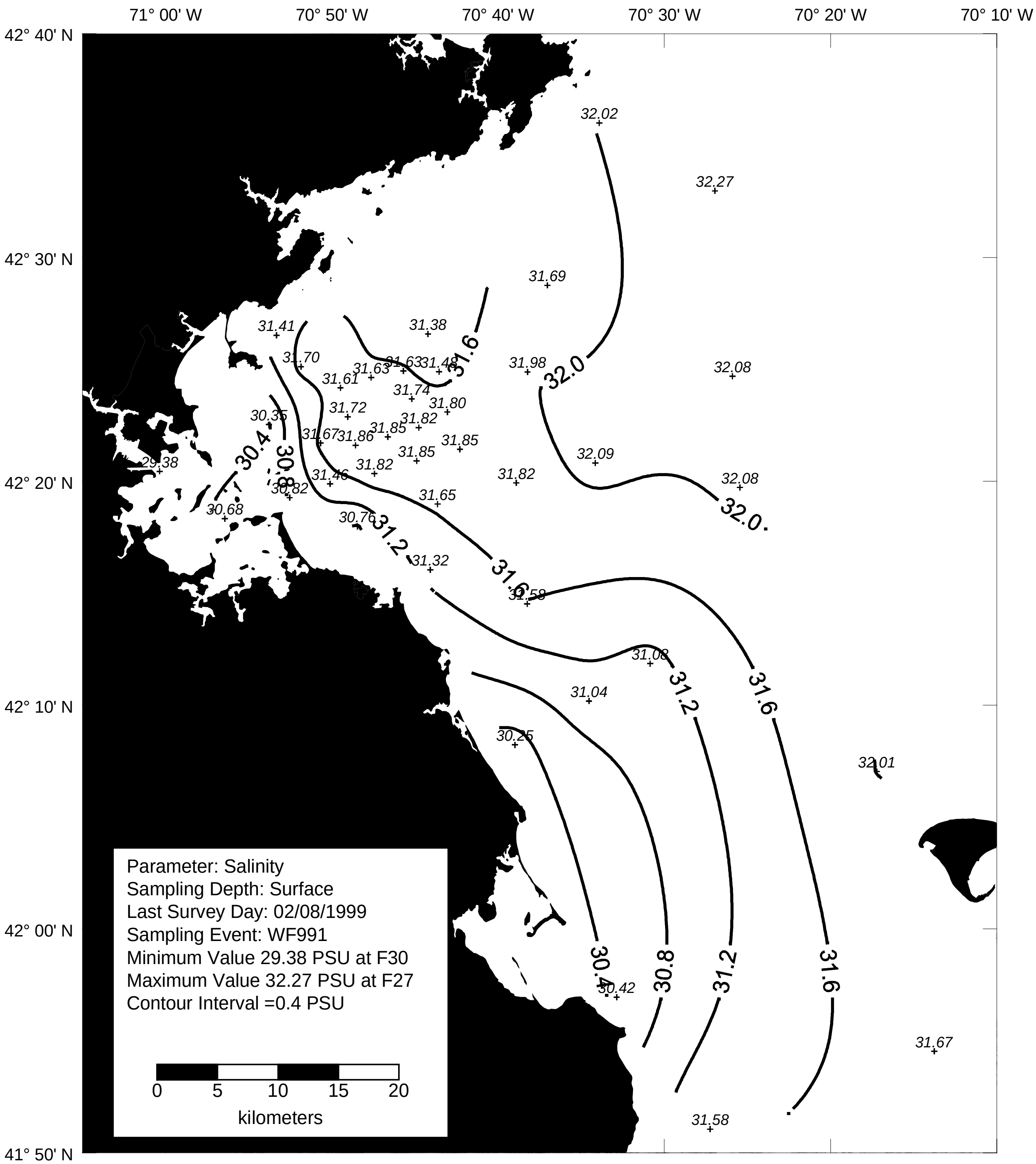


Figure 4-4. Salinity Surface Contour Plot for Farfield Survey WF991 (Feb 99)

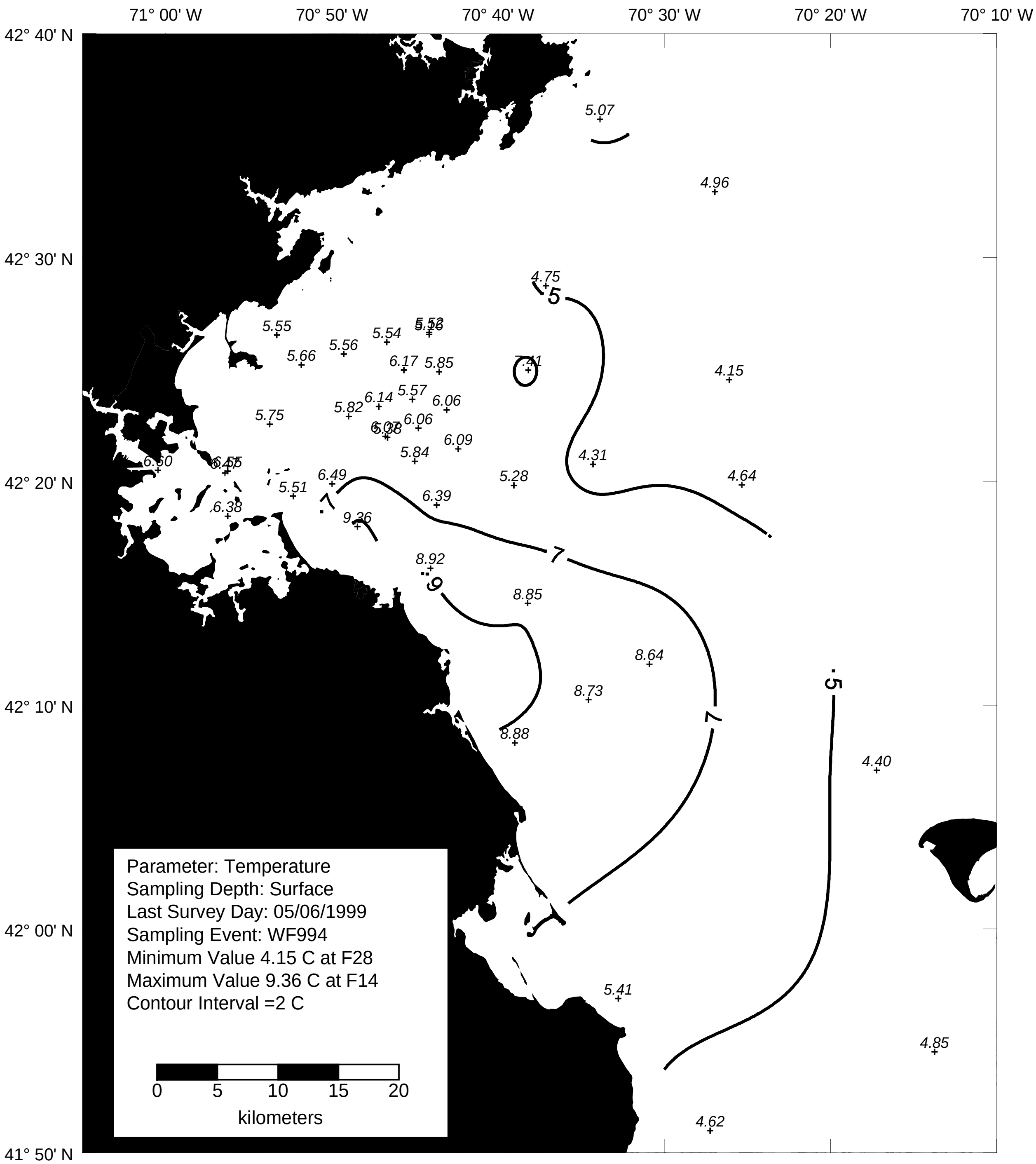


Figure 4-5. Temperature Surface Contour Plot for Farfield Survey WF994 (Apr 99)

Note: All data from the Cape Cod Bay, boundary, nearfield and Harbor areas were collected between April 1st and April 11th (see Figure 1-3). Southern coastal and offshore stations (N16F, F05, F06, F07, F10, F13, F14 and F19) were sampled on April 26th and May 6th.

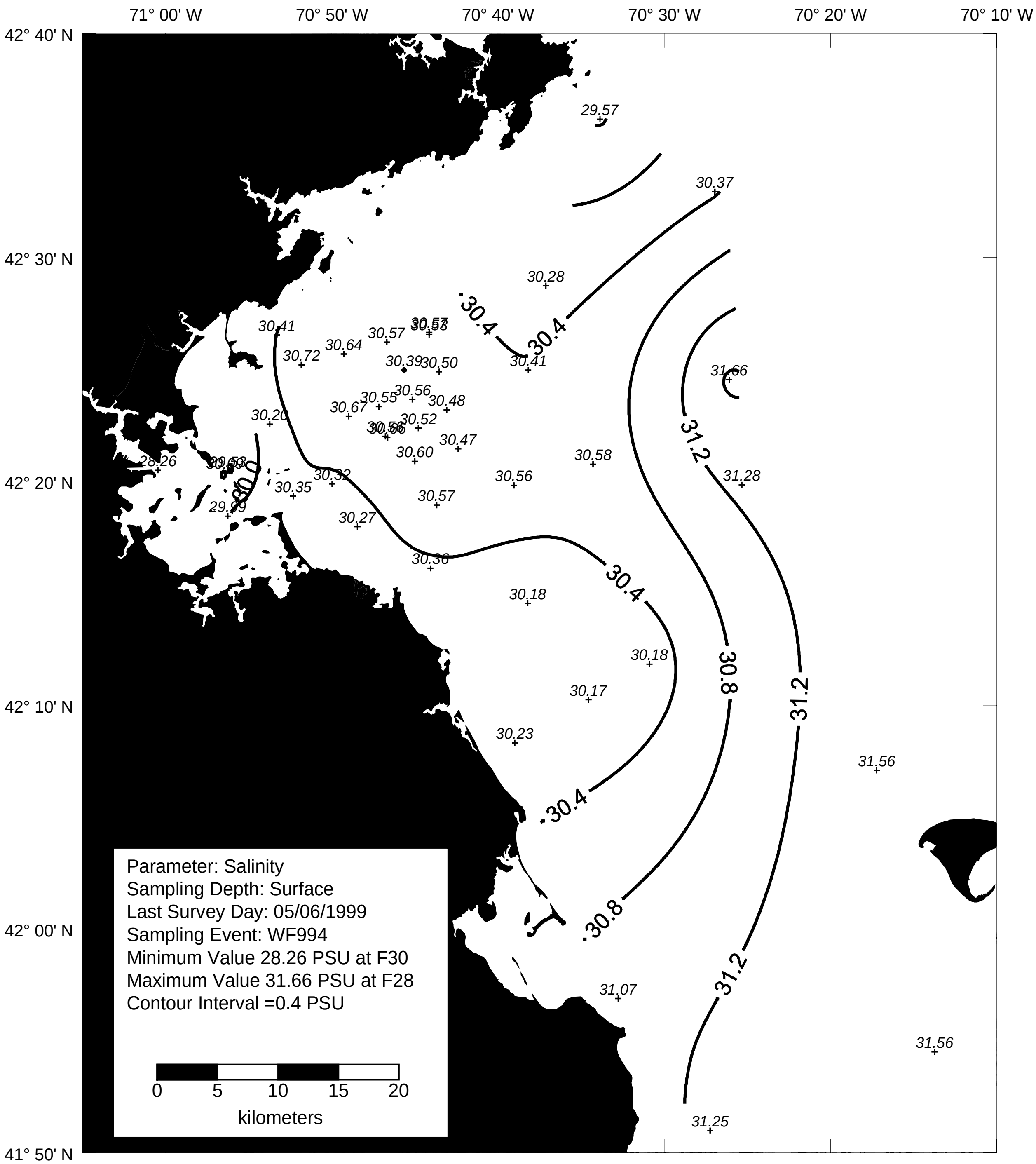


Figure 4-6. Salinity Surface Contour Plot for Farfield Survey WF994 (Apr 99)

Note: see Figure 4-5 for sample collection information.

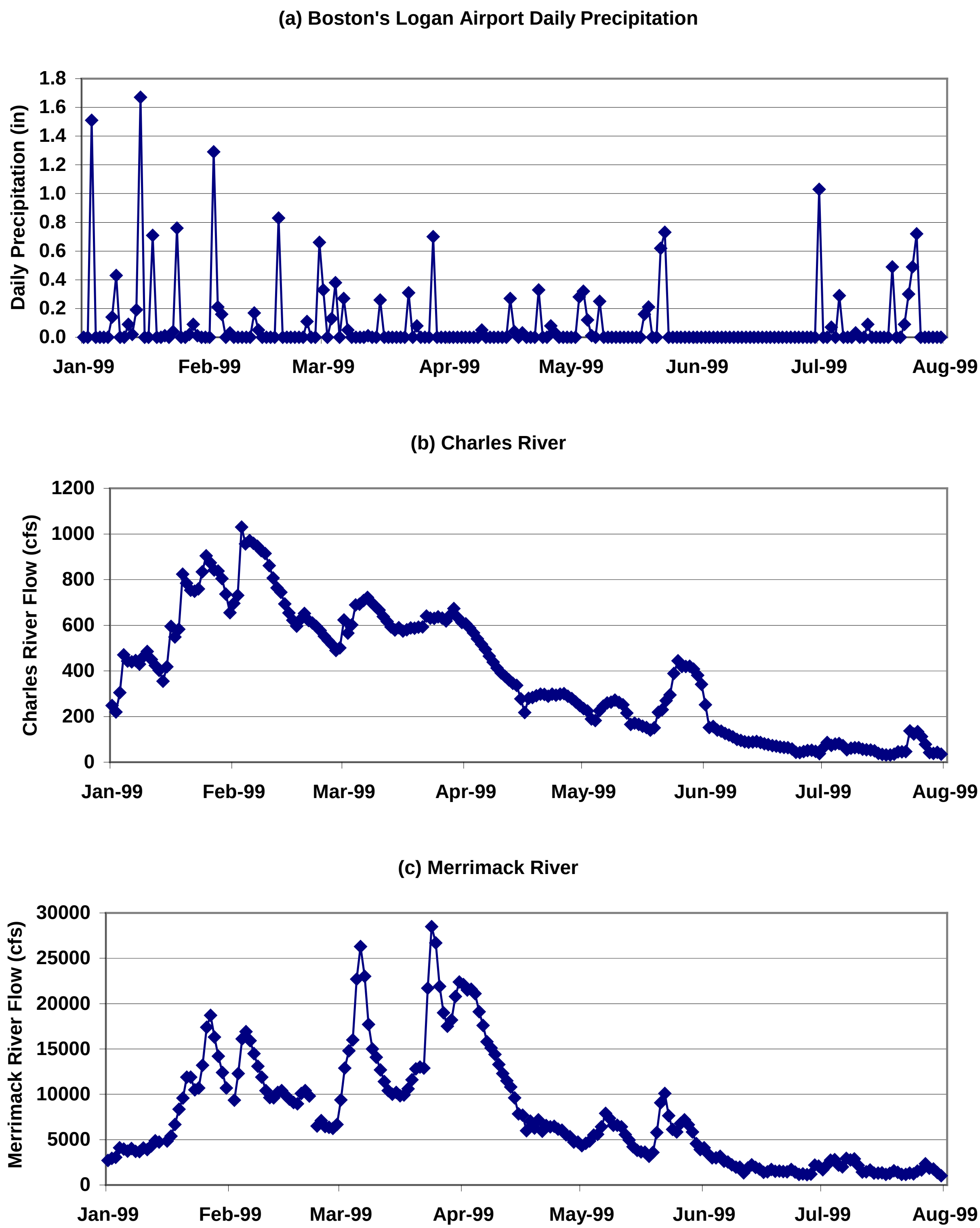
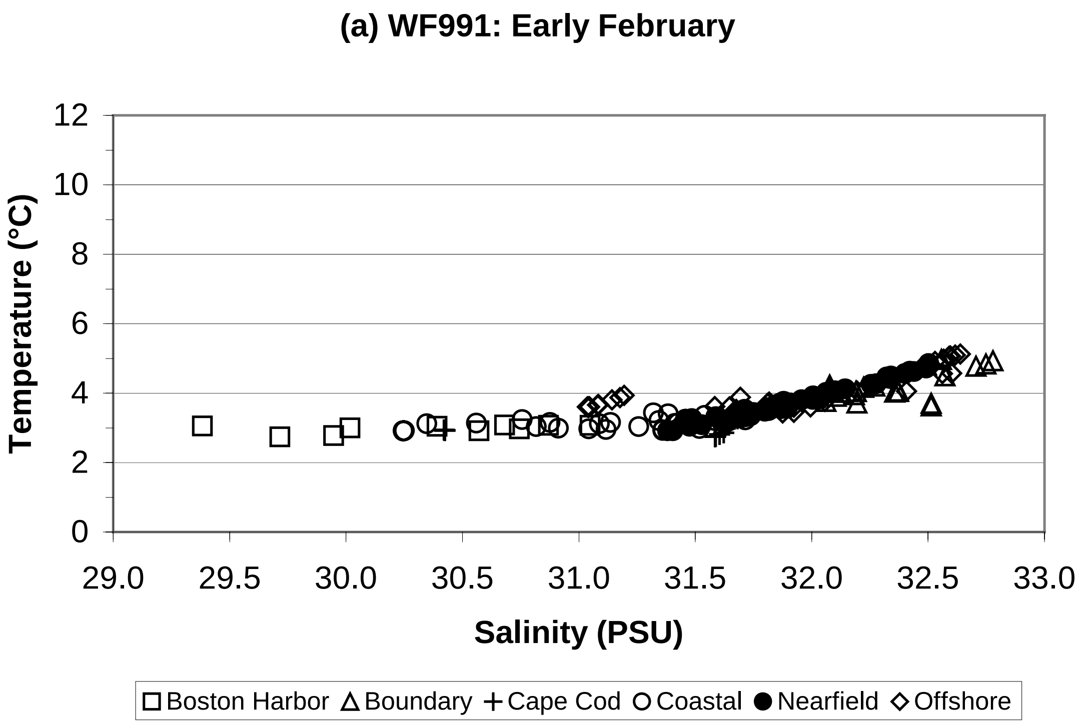


Figure 4-7. Precipitation at Logan Airport and River Discharges for the Charles and Merrimack Rivers



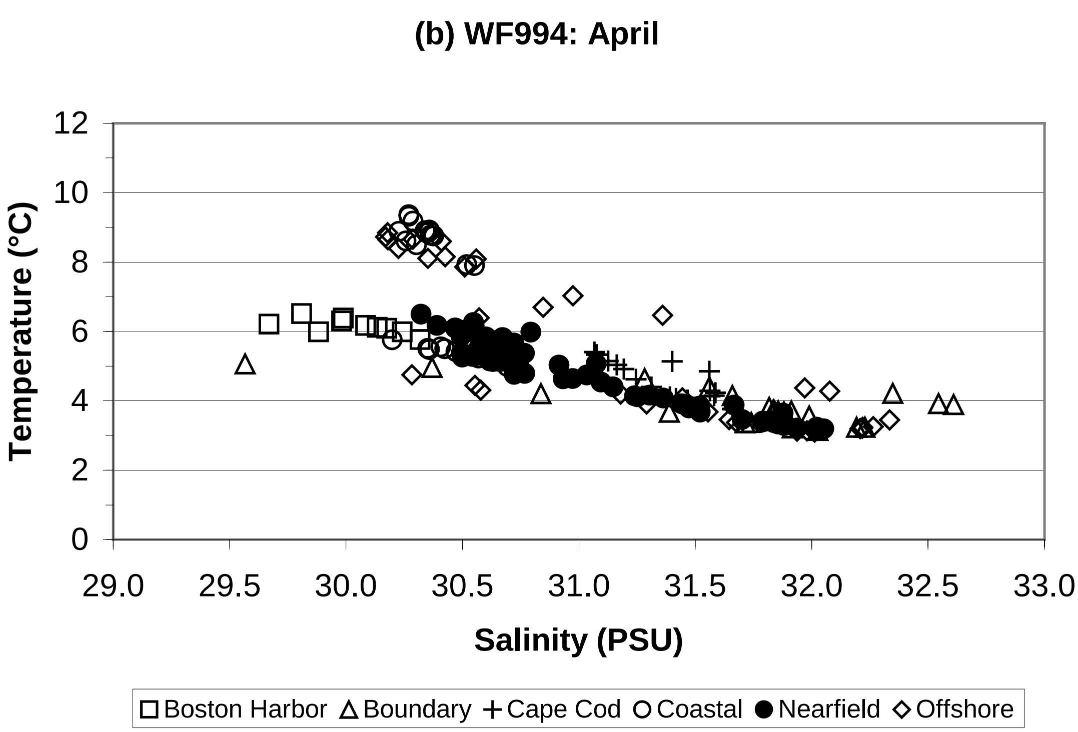


Figure 4-8. Temperature/Salinity Distribution for All Depths during WF991 (Feb 99) and WF994 (Apr 99) Surveys

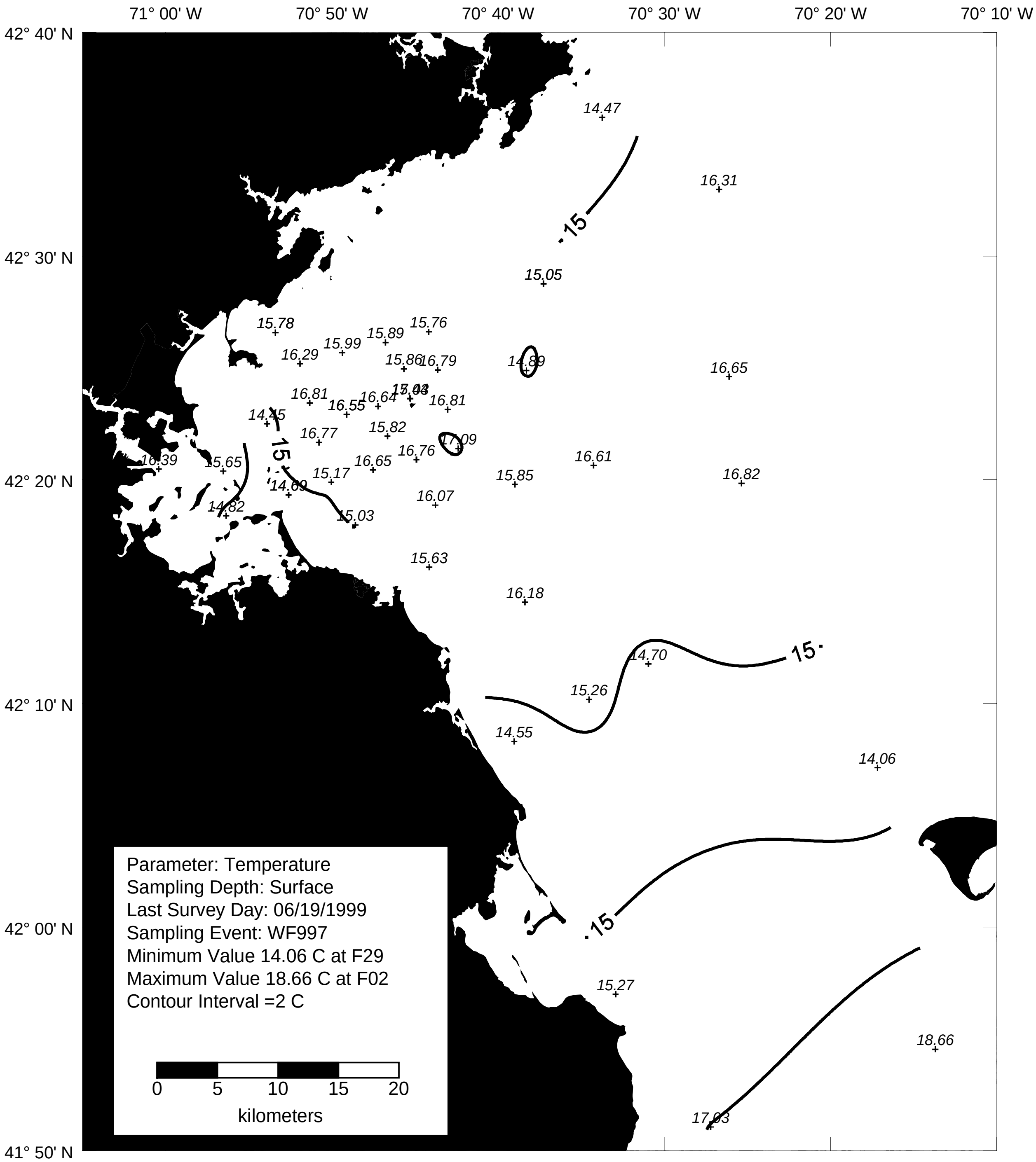


Figure 4-9. Temperature Surface Contour Plot for Farfield Survey WF997 (Jun 99)

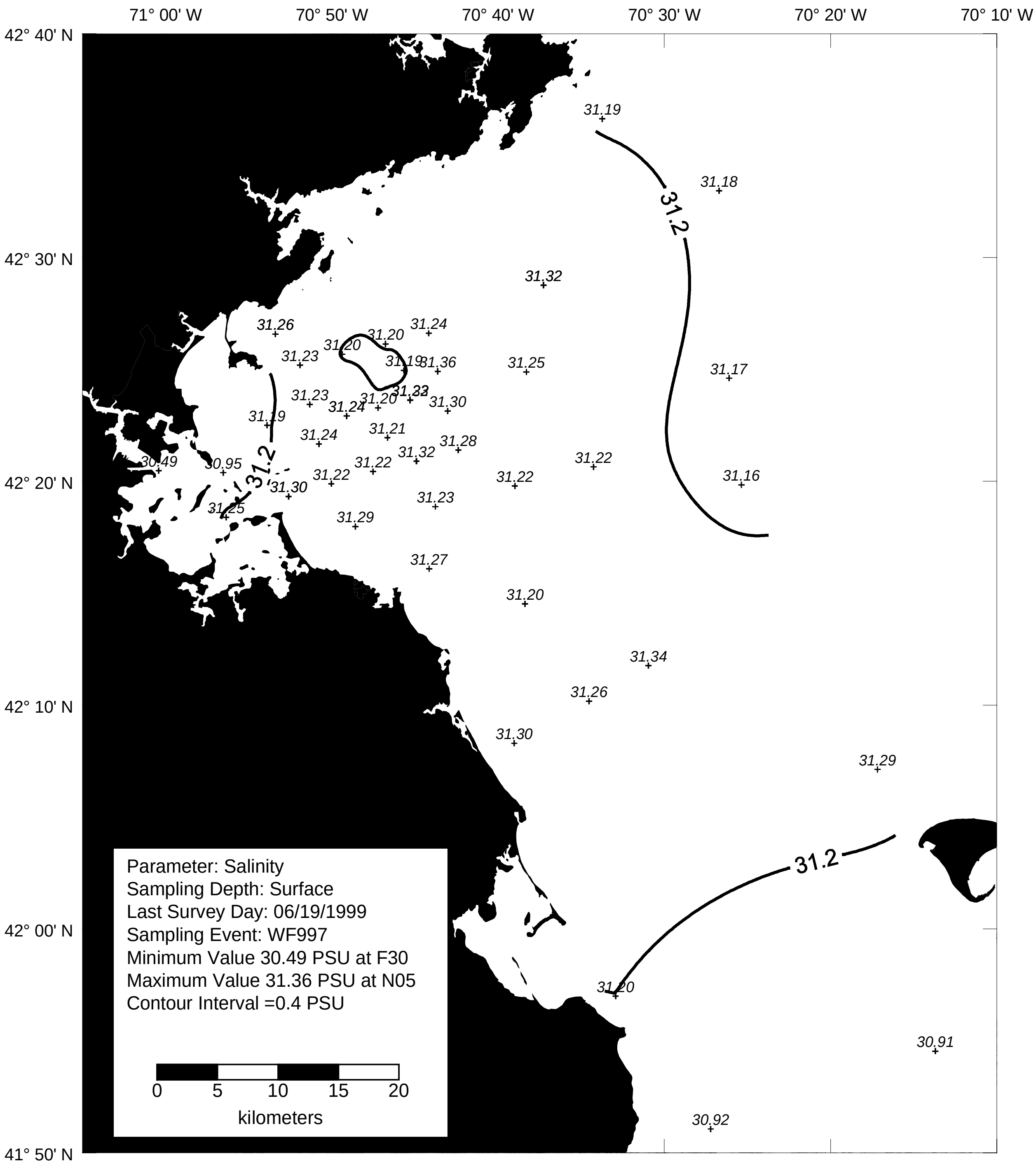


Figure 4-10. Salinity Surface Contour Plot for Farfield Survey WF997 (Jun 99)

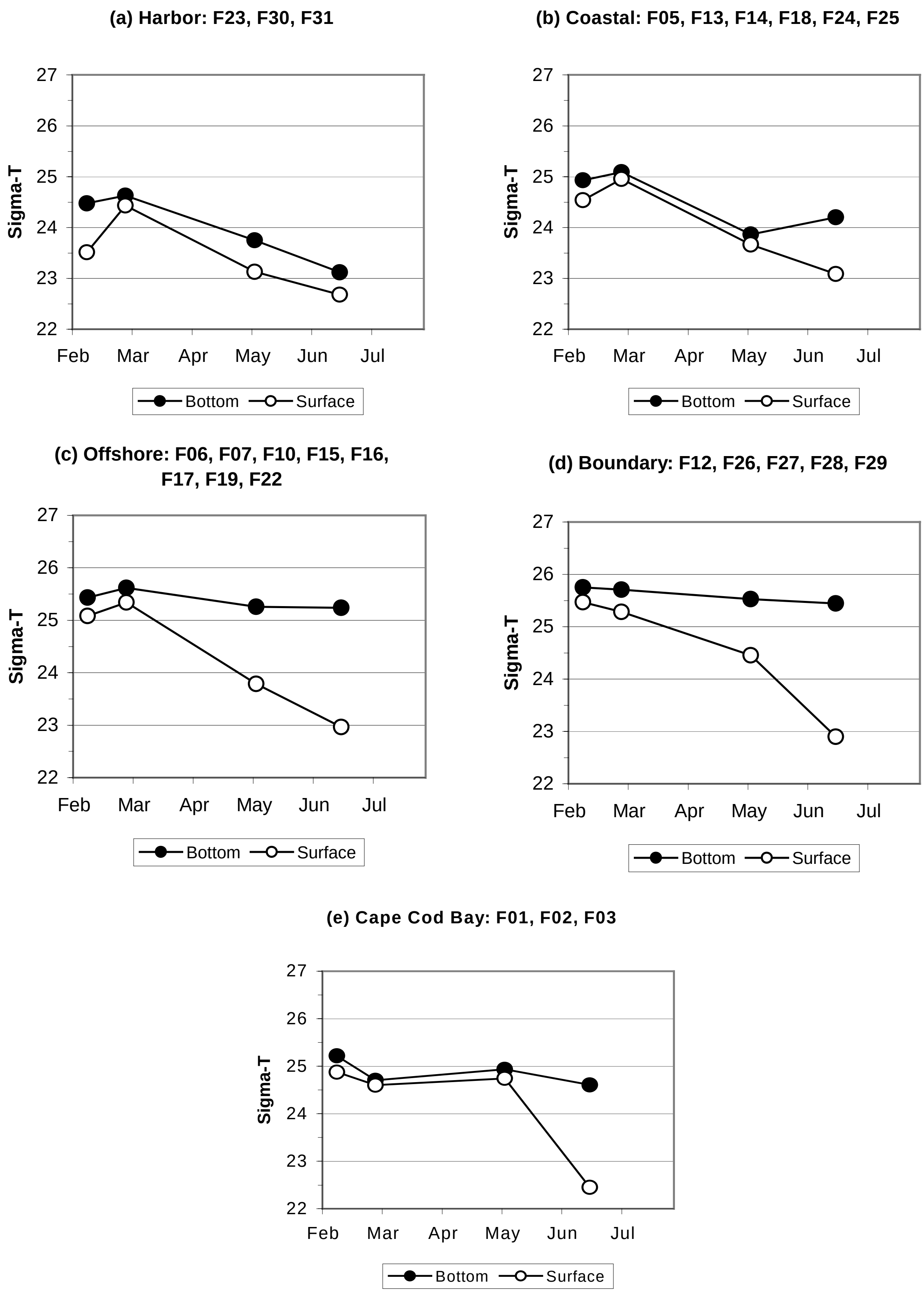


Figure 4-11. Time-Series of Average Surface and Bottom Water Density (σ_T) in the Farfield

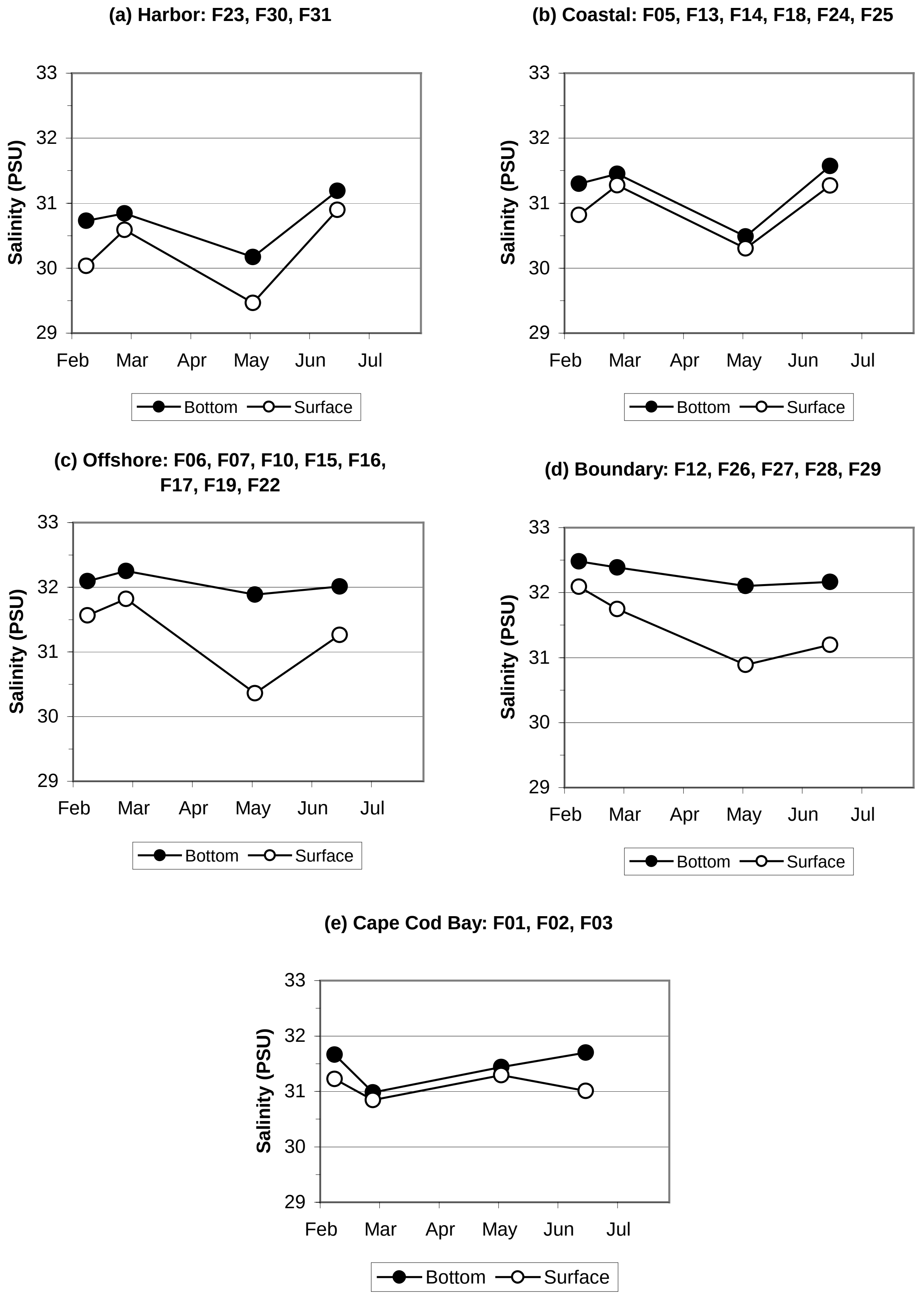


Figure 4-12. Time-Series of Average Surface and Bottom Water Salinity (PSU) in the Farfield

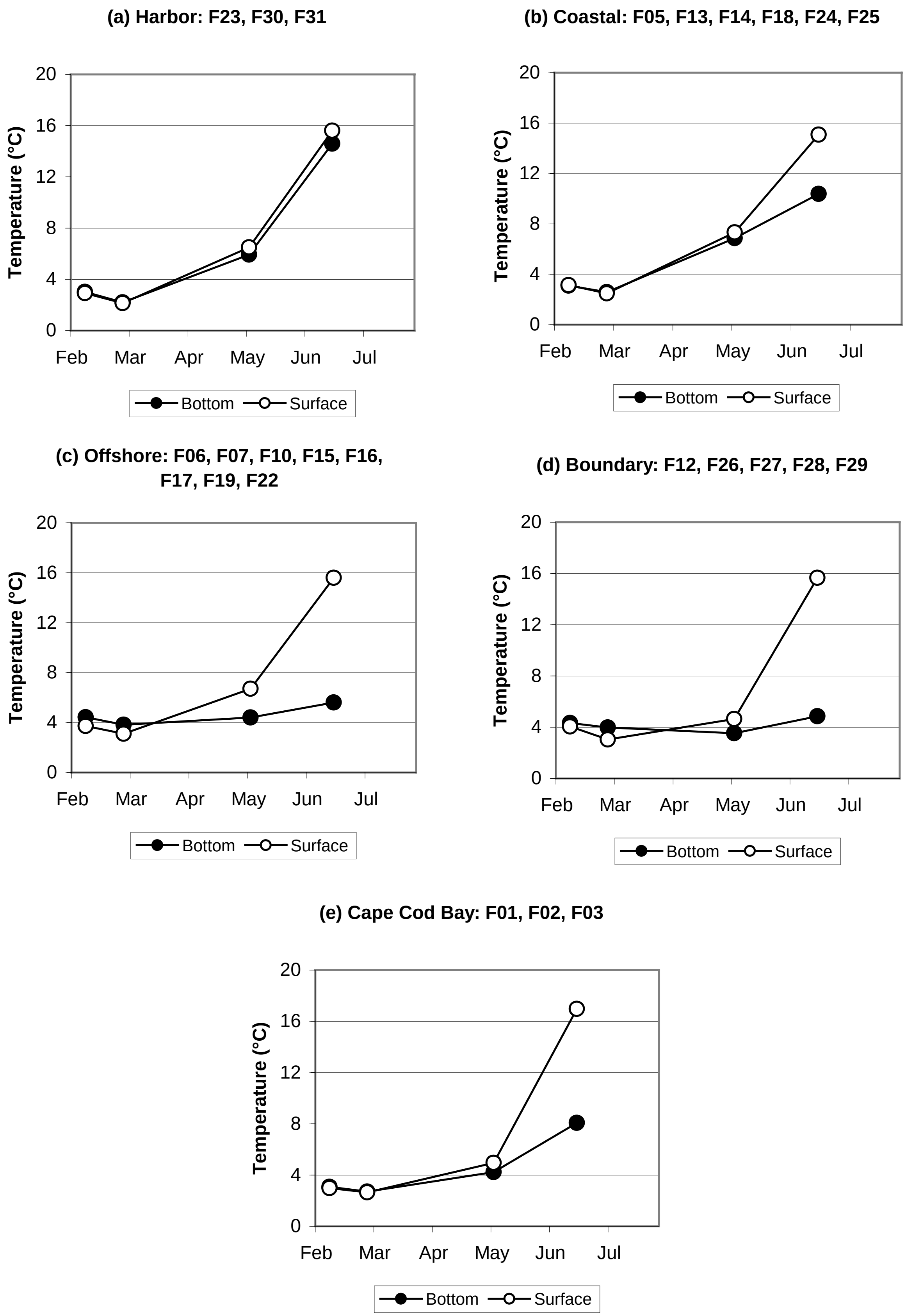


Figure 4-13. Time-Series of Average Surface and Bottom Temperature in the Farfield

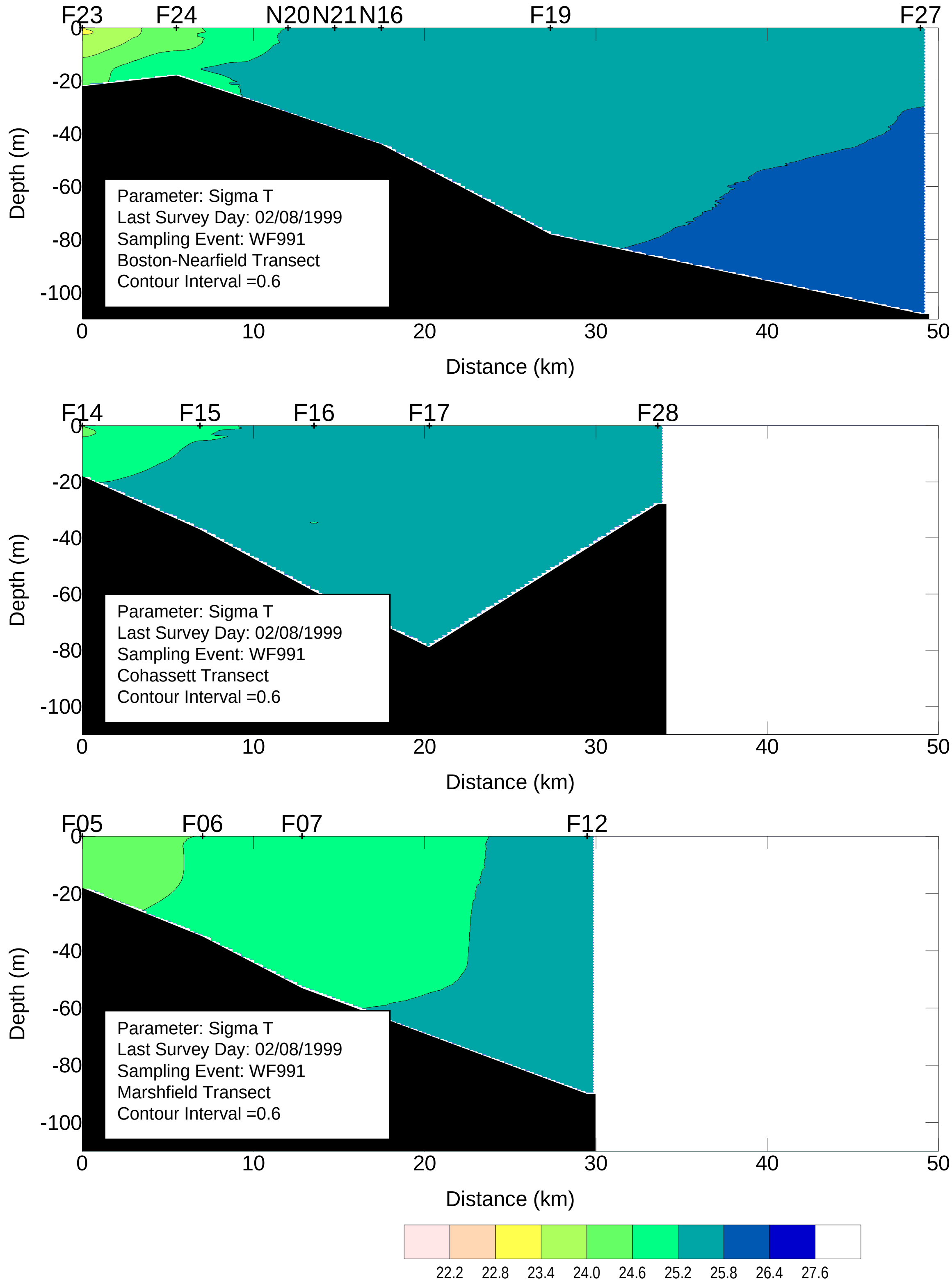


Figure 4-14. Sigma-T Vertical Transects for Farfield Survey WF991 (Feb 99)

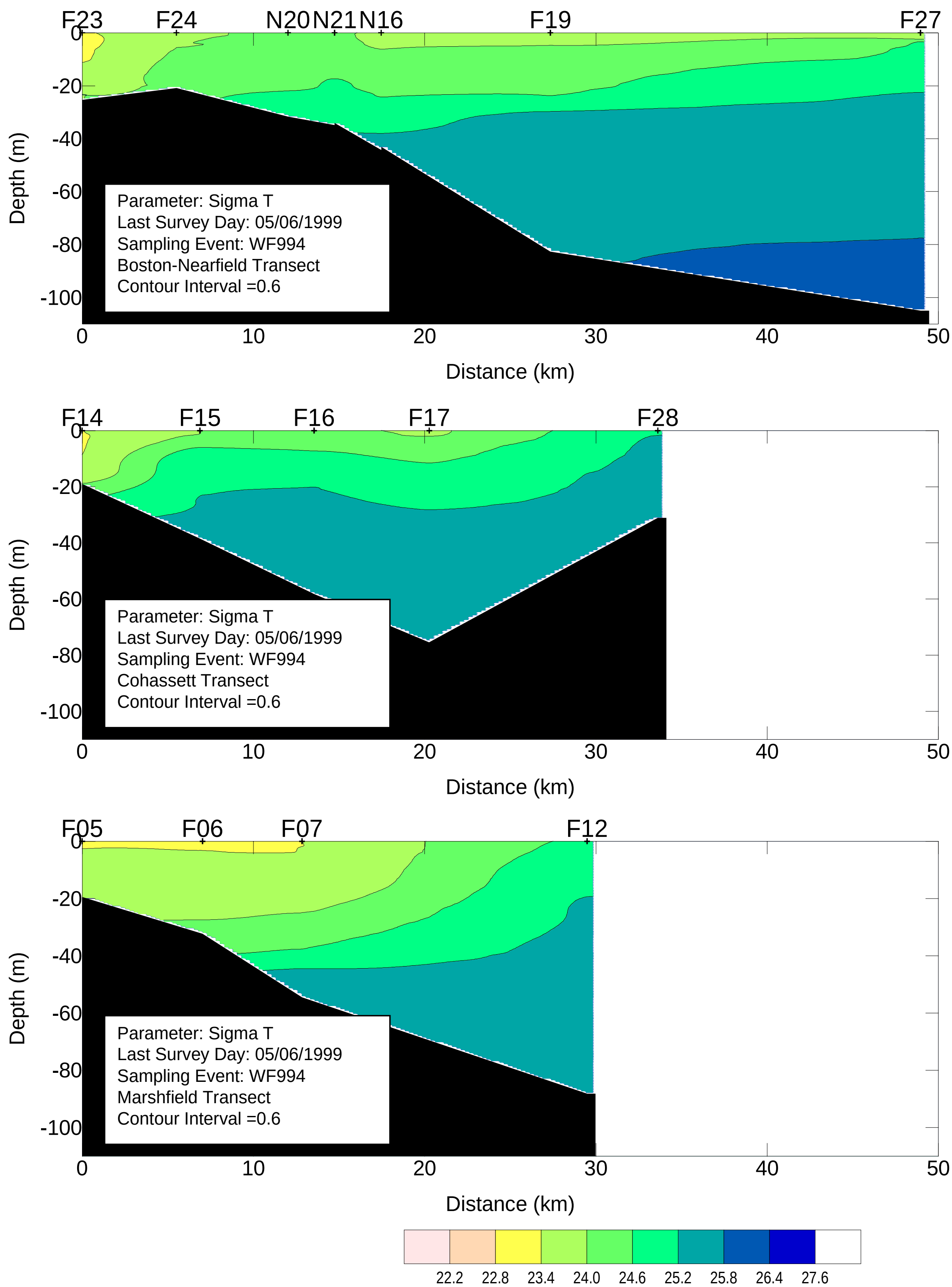


Figure 4-15. Sigma-T Vertical Transect for Farfield Survey WF994 (Apr 99)

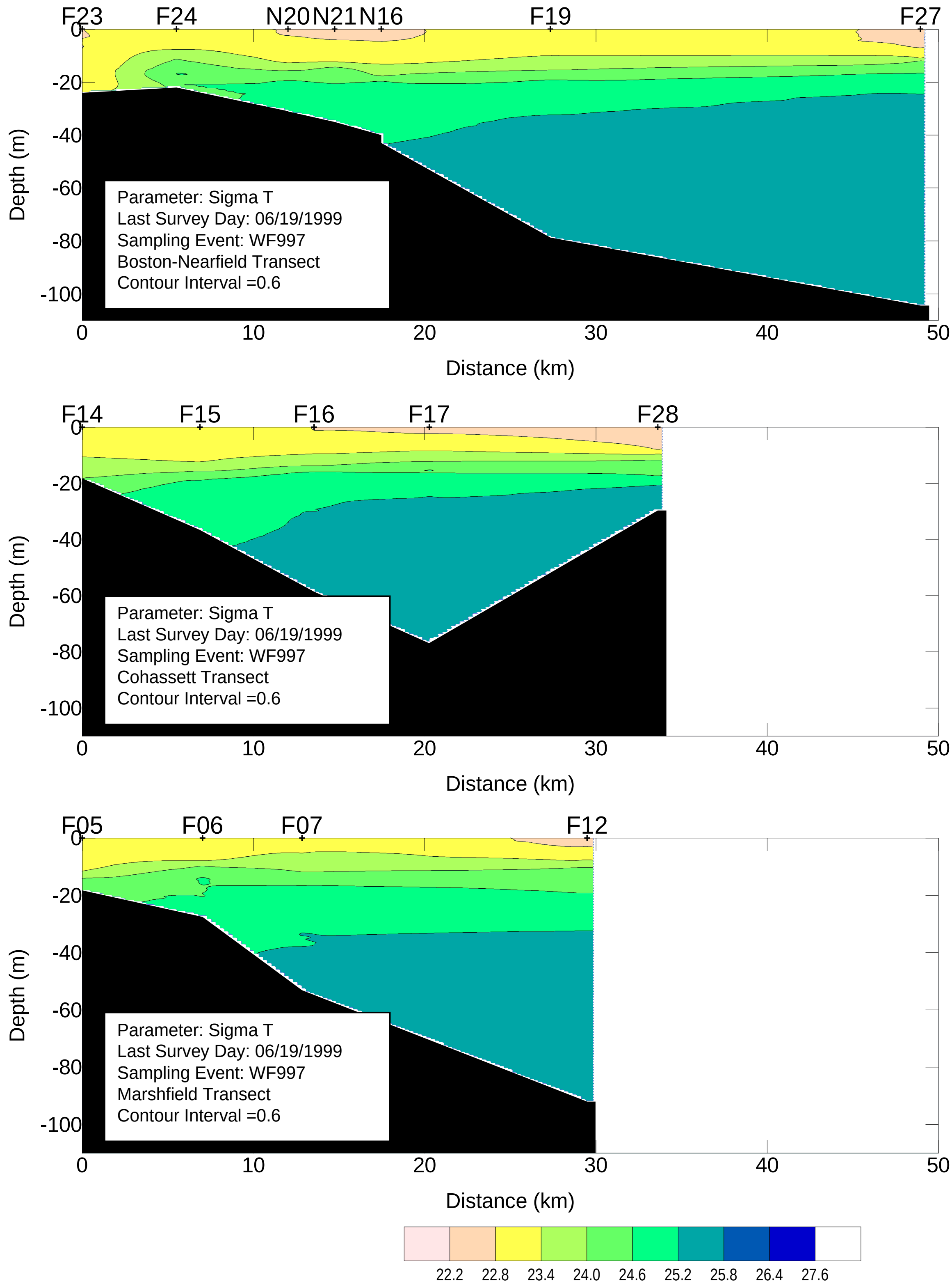


Figure 4-16. Sigma-T Vertical Transect for Farfield Survey WF997 (Jun 99)

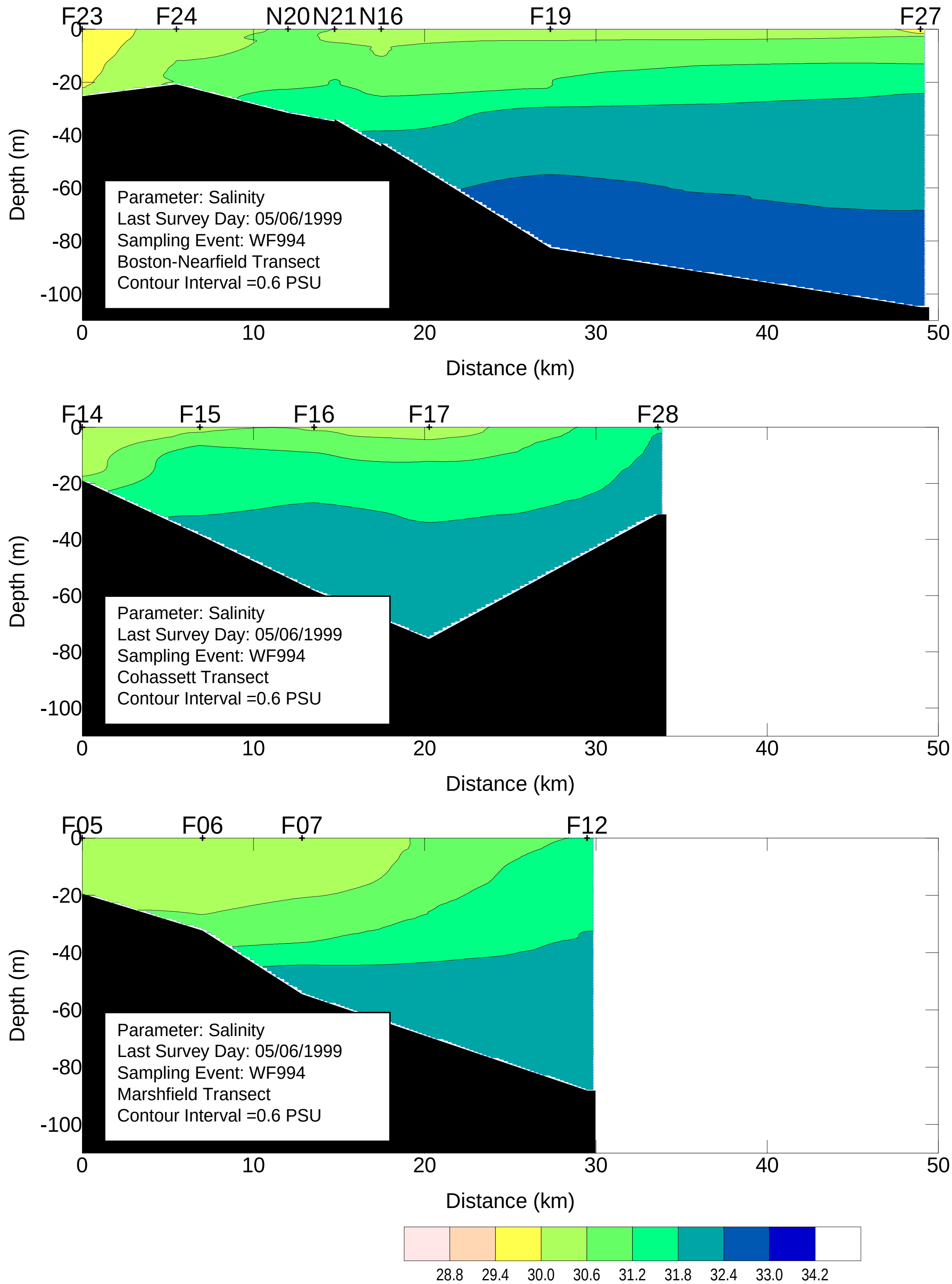


Figure 4-17. Salinity Vertical Transect for Farfield Survey WF994 (Apr 99)

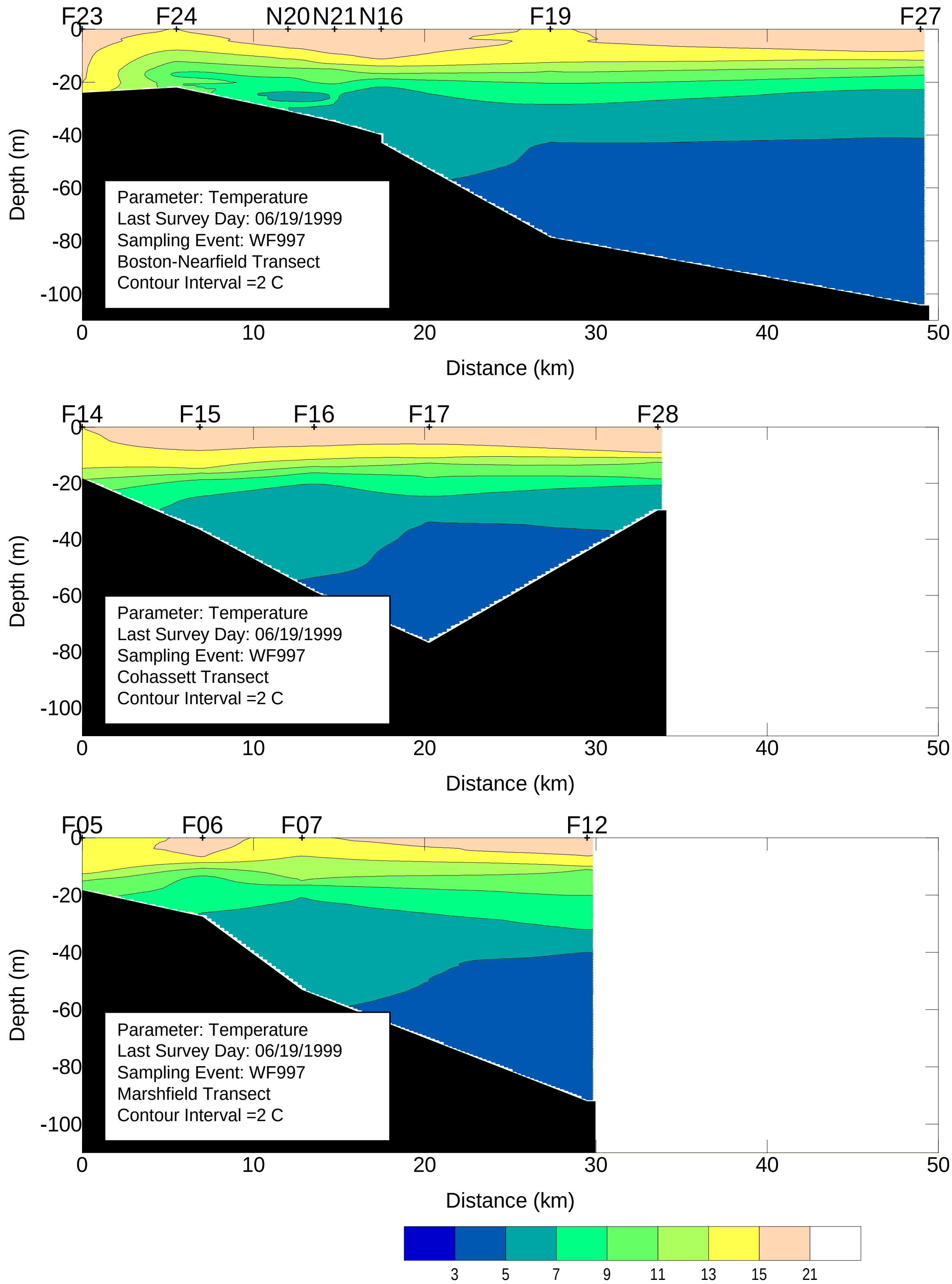


Figure 4-18. Temperature Vertical Transect for Farfield Survey WF997 (Jun 99)

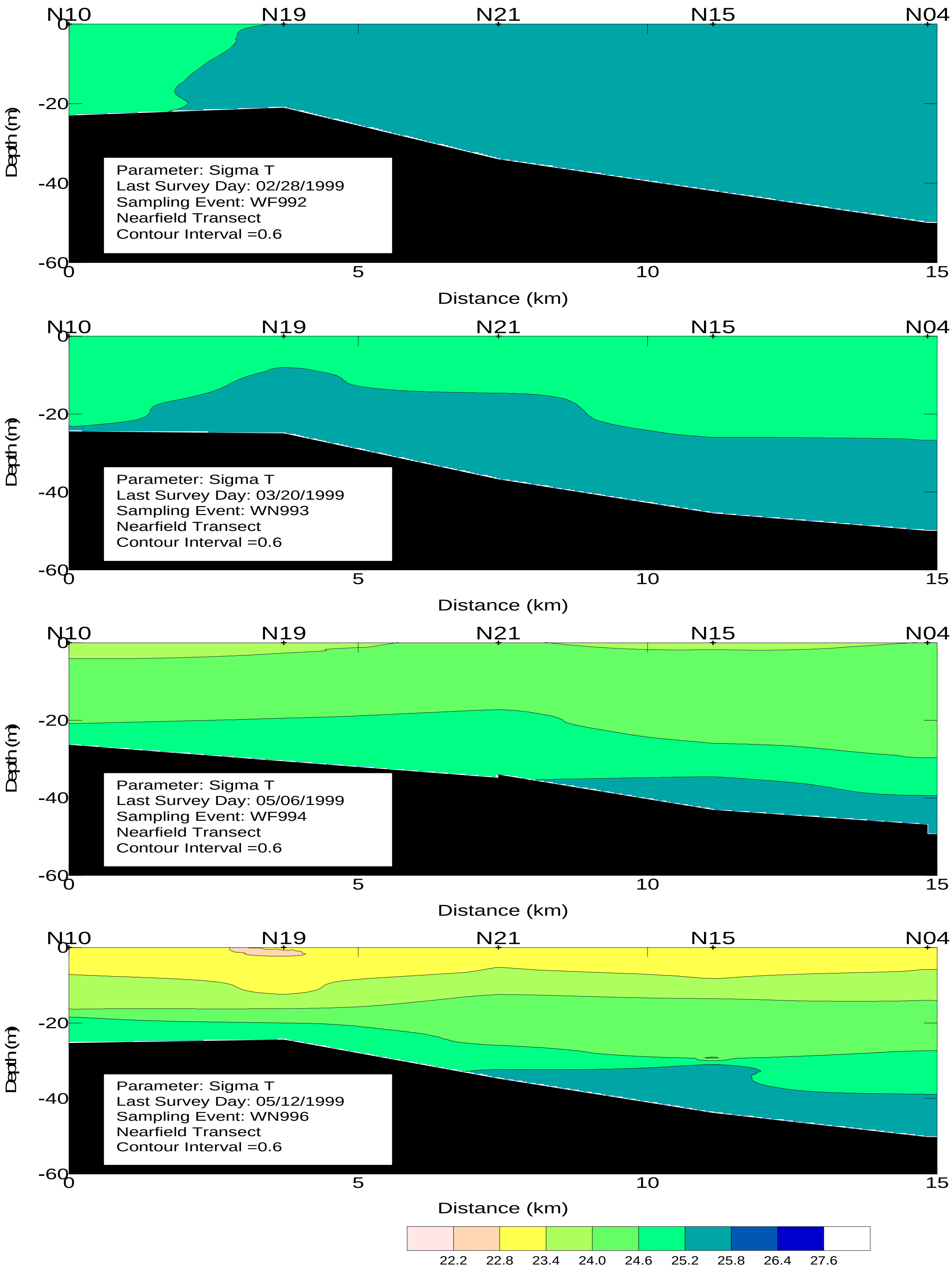


Figure 4-19. Sigma-T Vertical Nearfield Transects for Survey WF992, WN993, WF994 and WN996

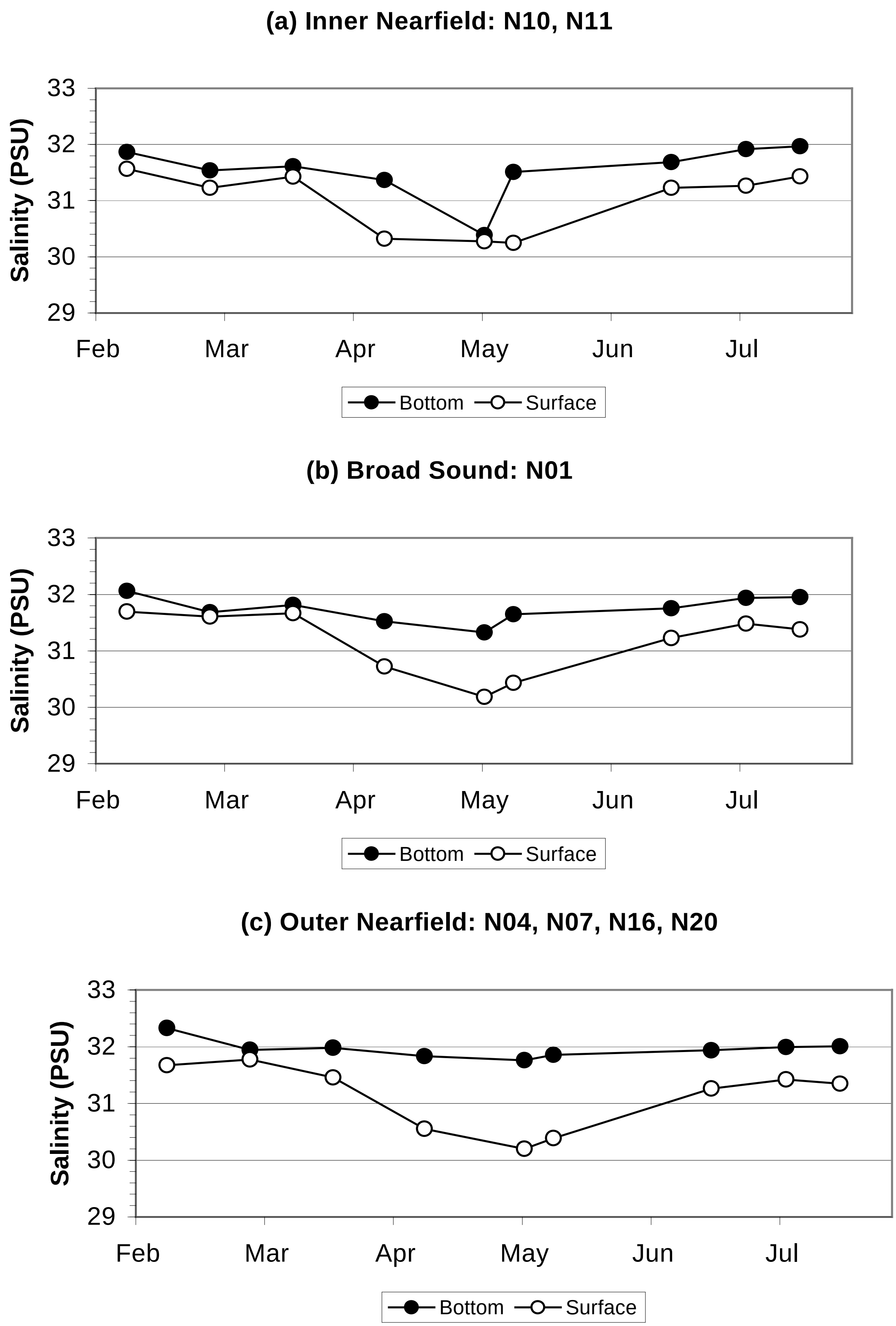


Figure 4-20. Time-Series of Average Surface and Bottom Salinity (PSU) in the Nearfield

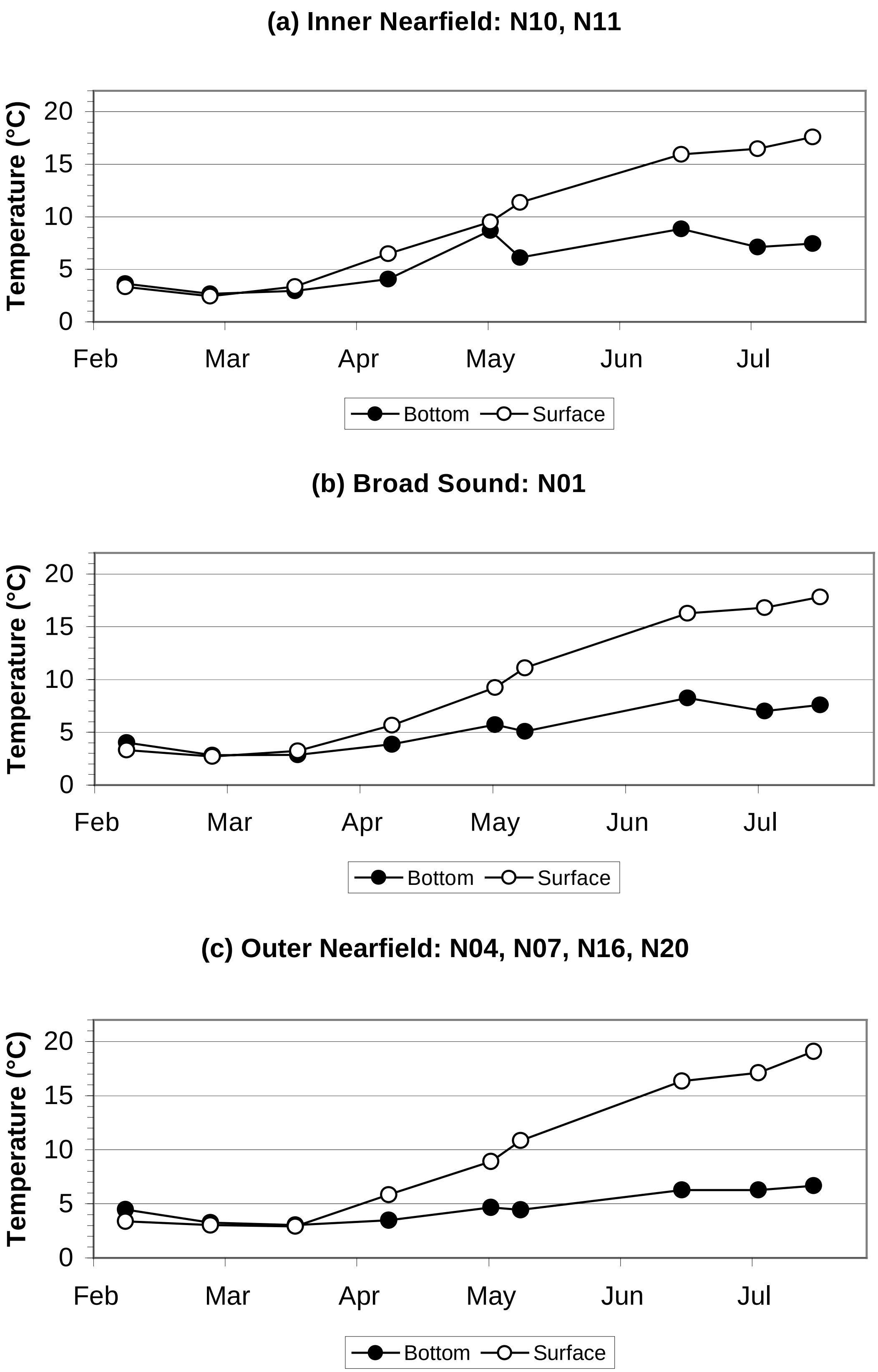


Figure 4-21. Time-Series of Average Surface and Bottom Temperature (°C) in the Nearfield

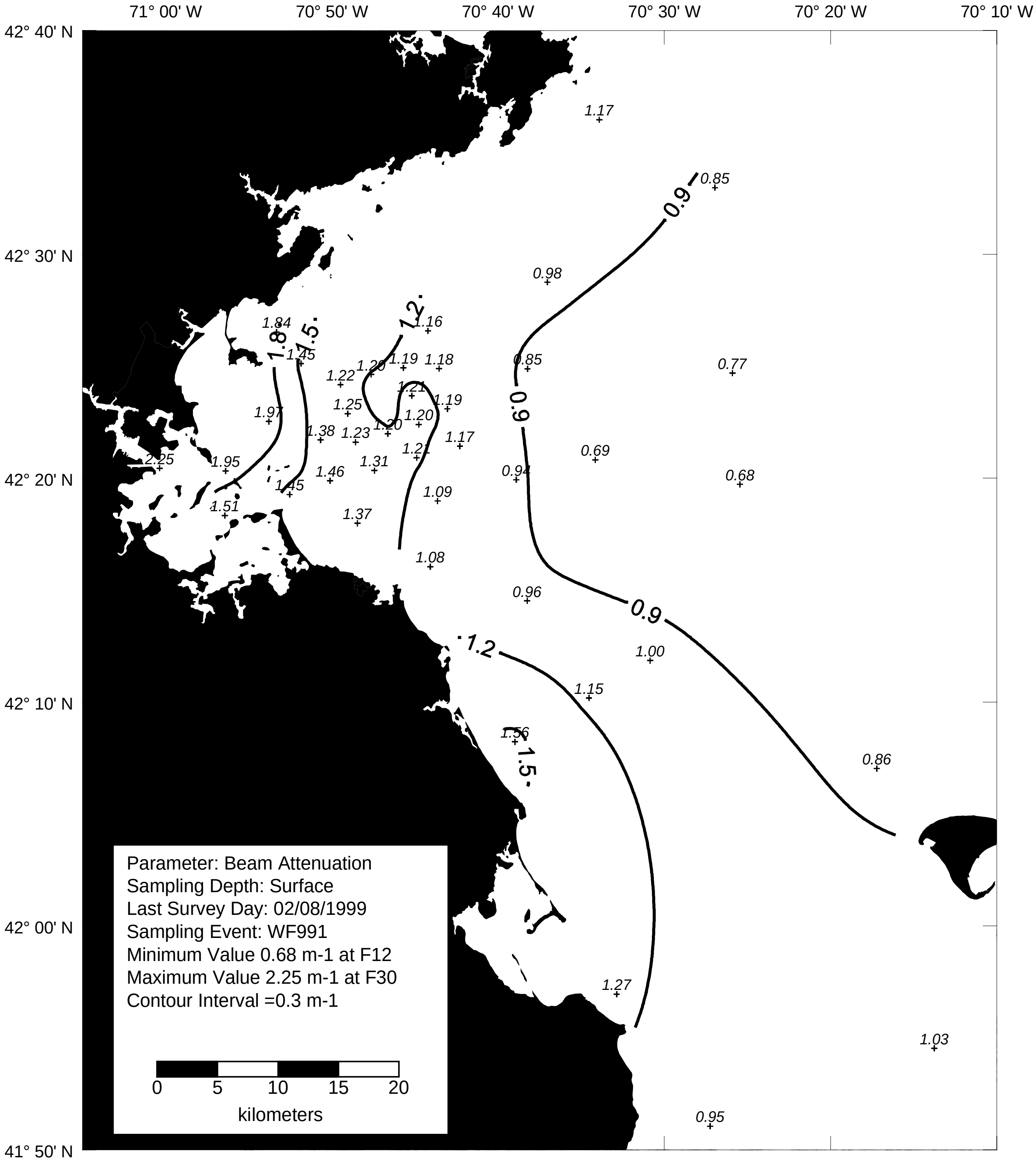


Figure 4-22. Beam Attenuation Surface Contour Plot for Farfield Survey WF991 (Feb 99)

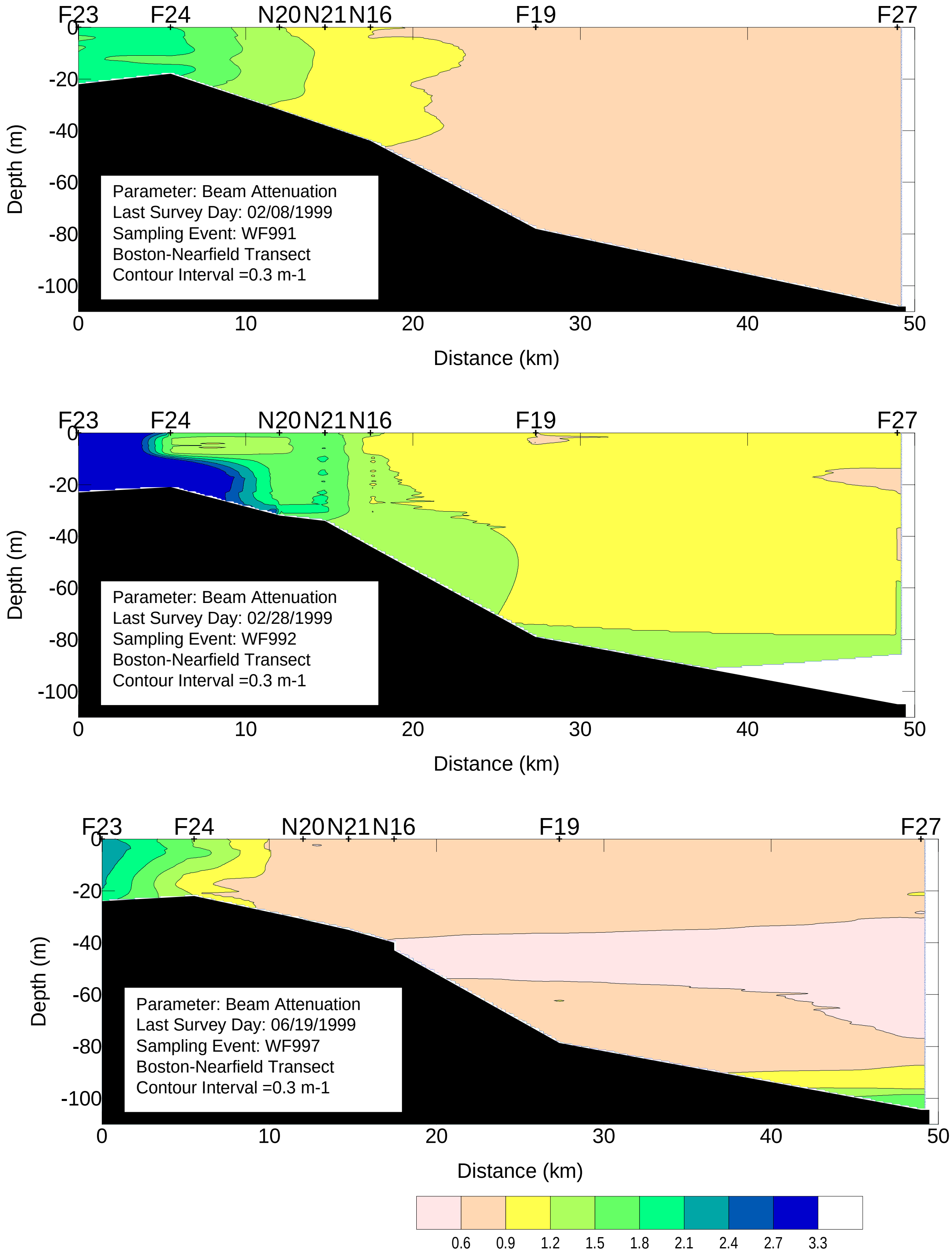


Figure 4-23. Beam Attenuation Vertical Boston-Nearfield Transects for Surveys WF991, WF992, and WF997

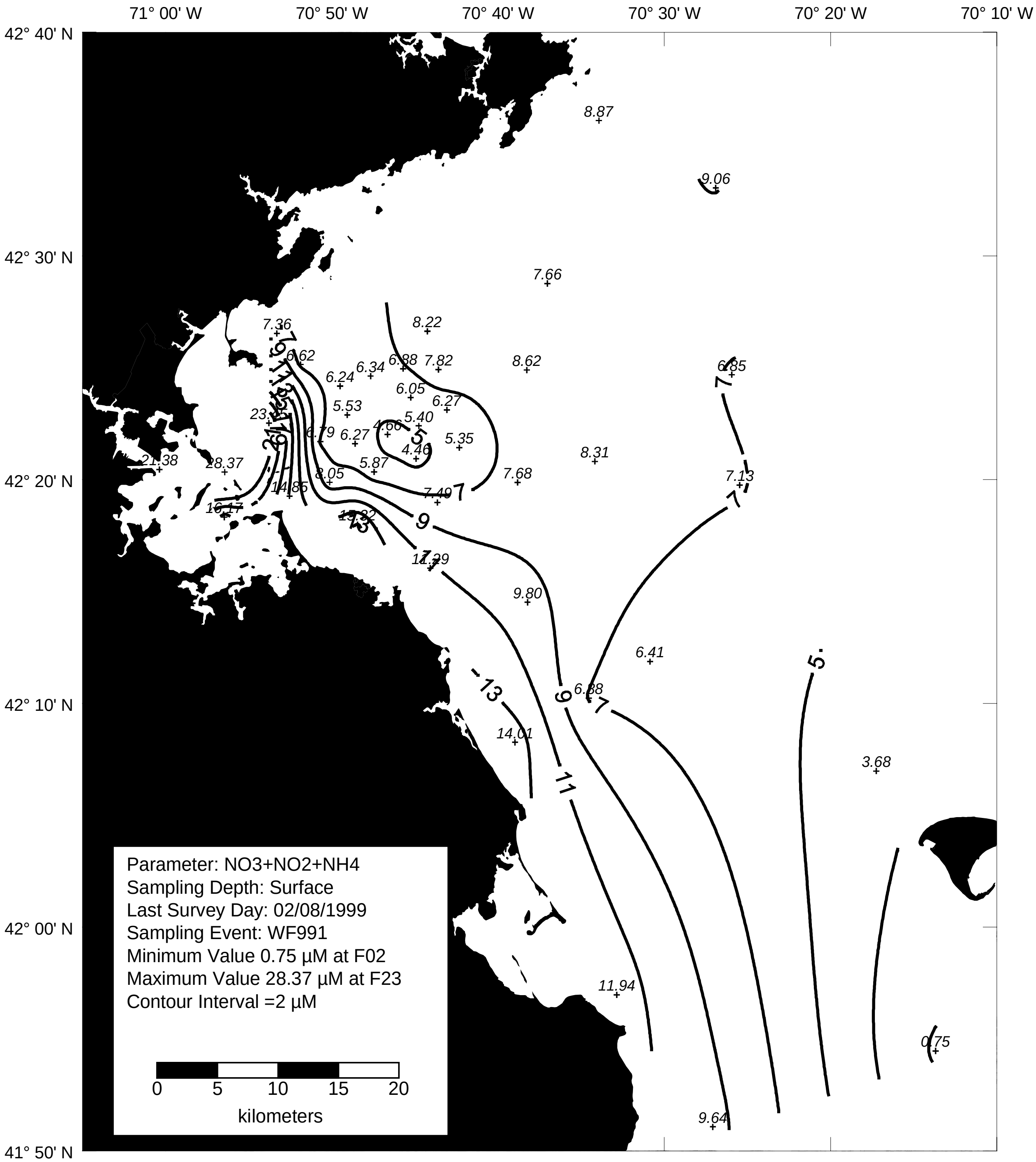


Figure 4-24. DIN Surface Contour Plot for Farfield Survey WF991 (Feb 99)

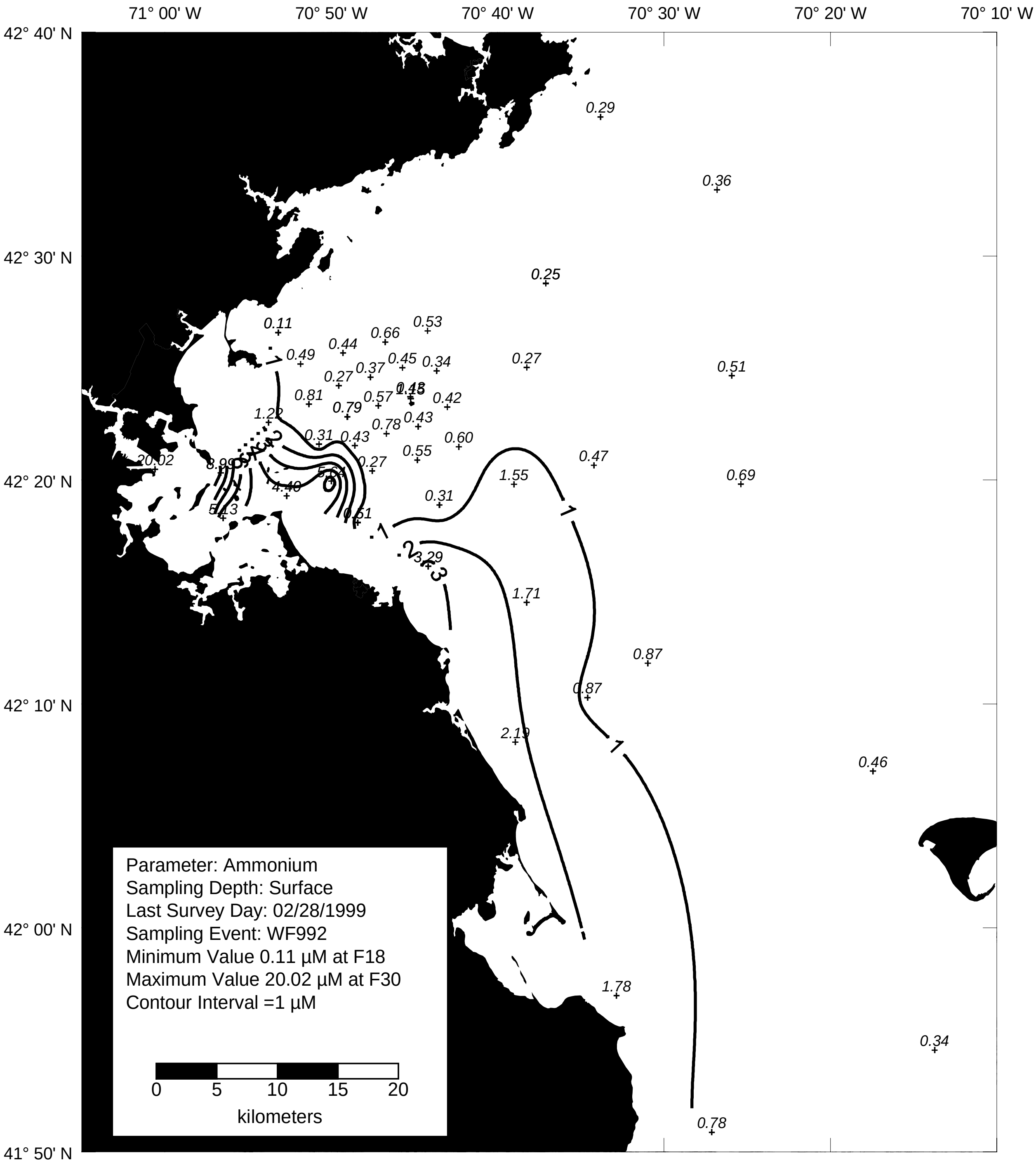


Figure 4-25. Ammonium Surface Contour Plot for Farfield Survey WF992 (Feb 99)

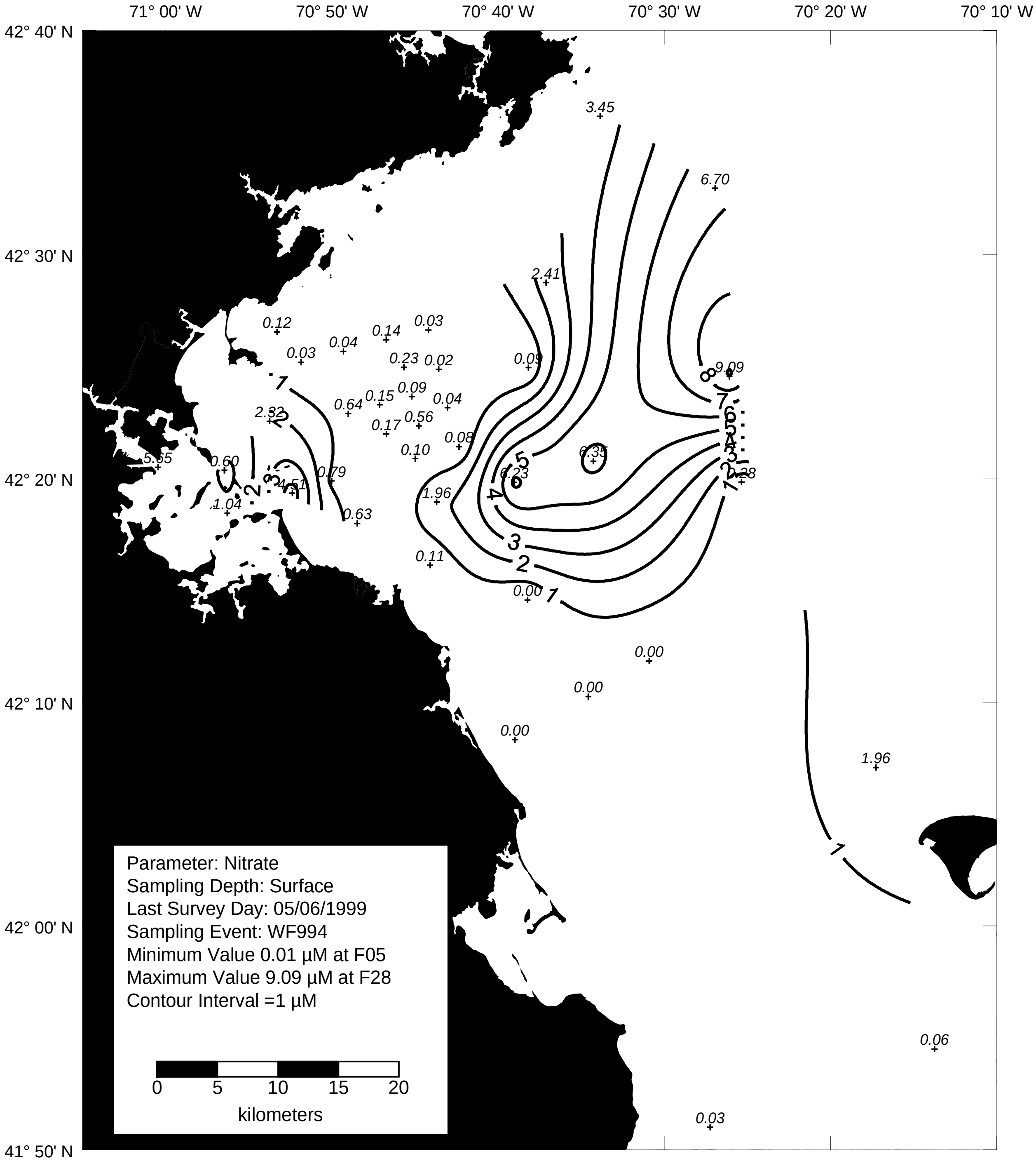


Figure 4-26. Nitrate Surface Contour Plot for Farfield Survey WF994 (Apr 99)

Note: see Figure 4-5 for sample collection information.

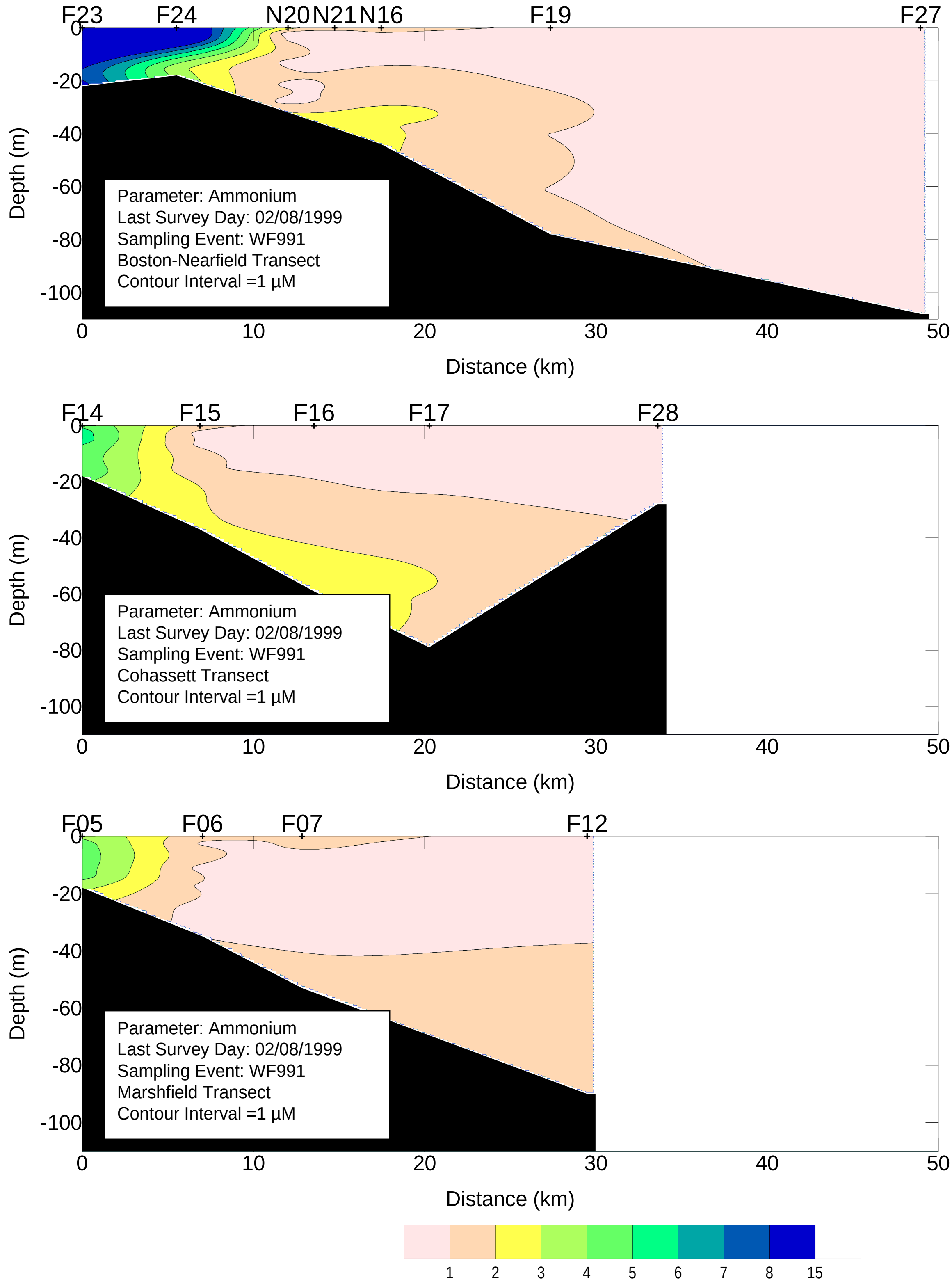


Figure 4-27. Ammonium Vertical Transect for Farfield Survey WF991 (Feb 99)

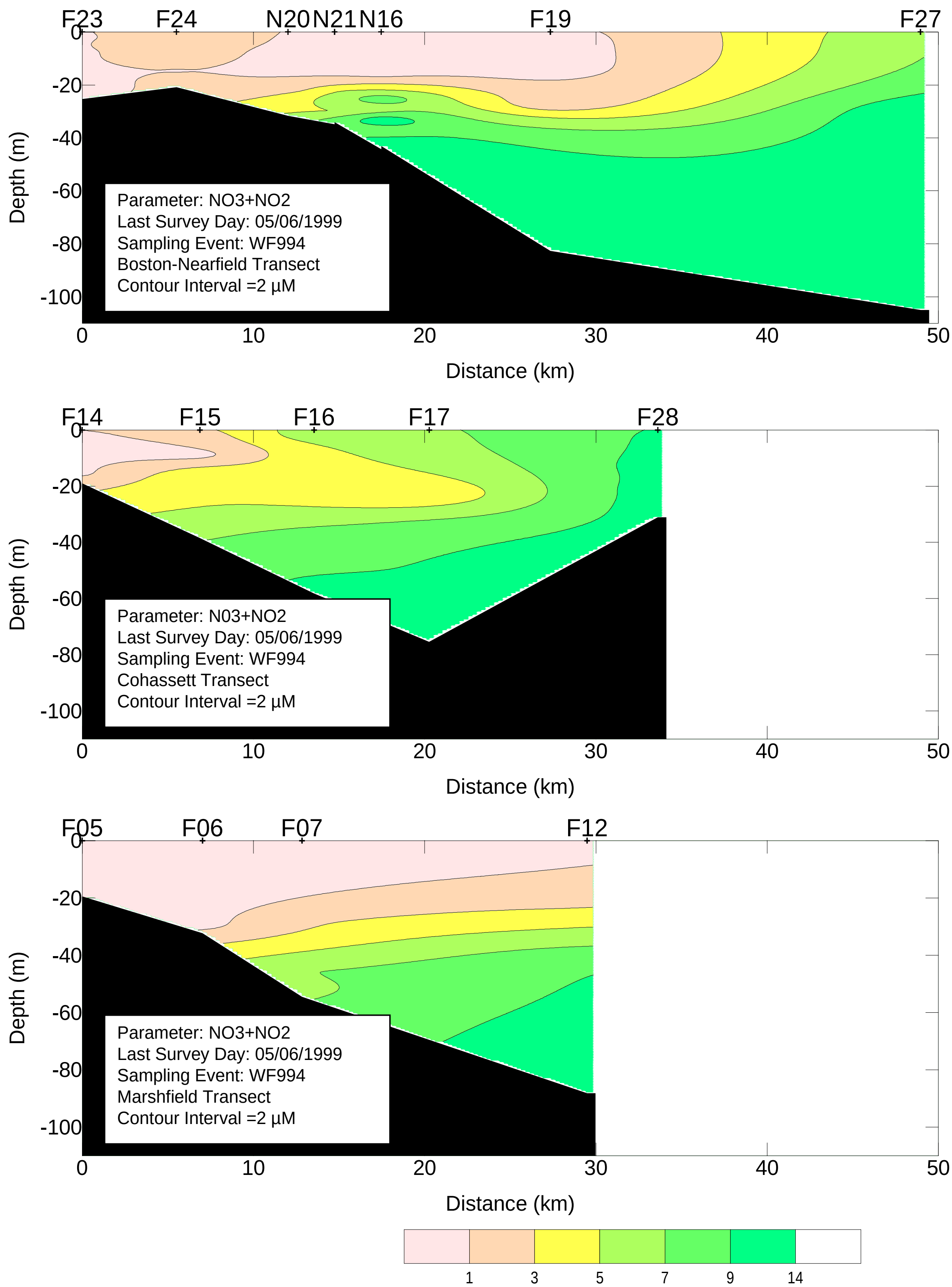
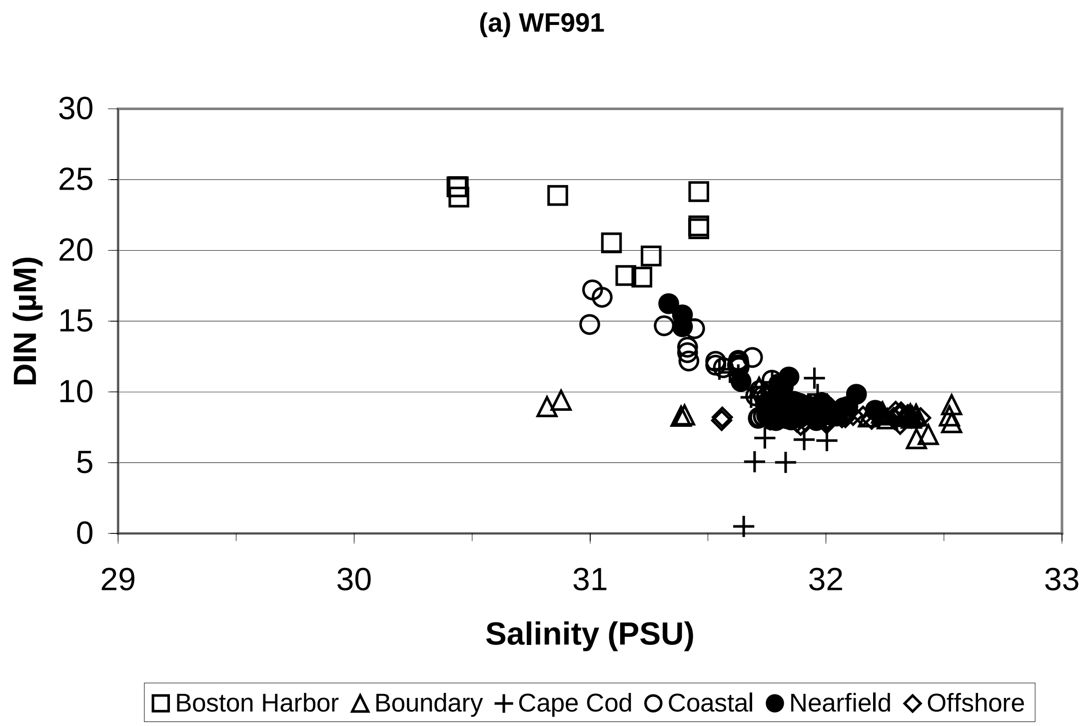


Figure 4-28. Nitrate Plus Nitrite Vertical Transect Plots for Farfield Survey WF994 (Apr 99)



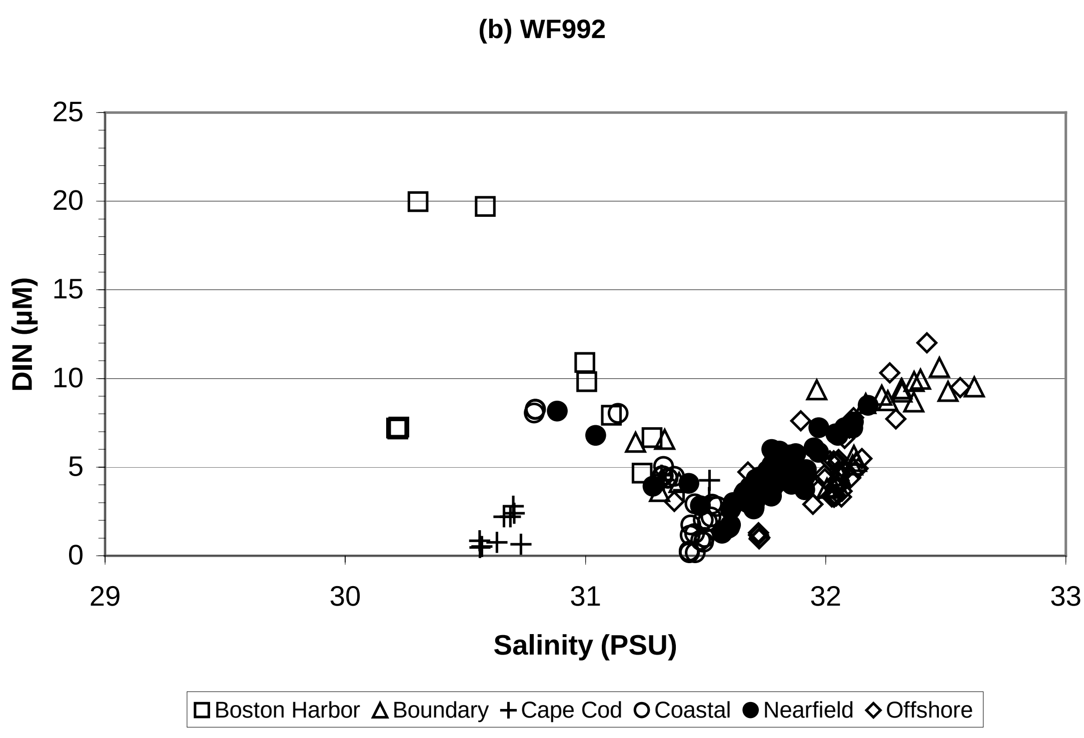


Figure 4-29. DIN vs. Salinity for All Depths during Farfield Surveys WF991 and WF992

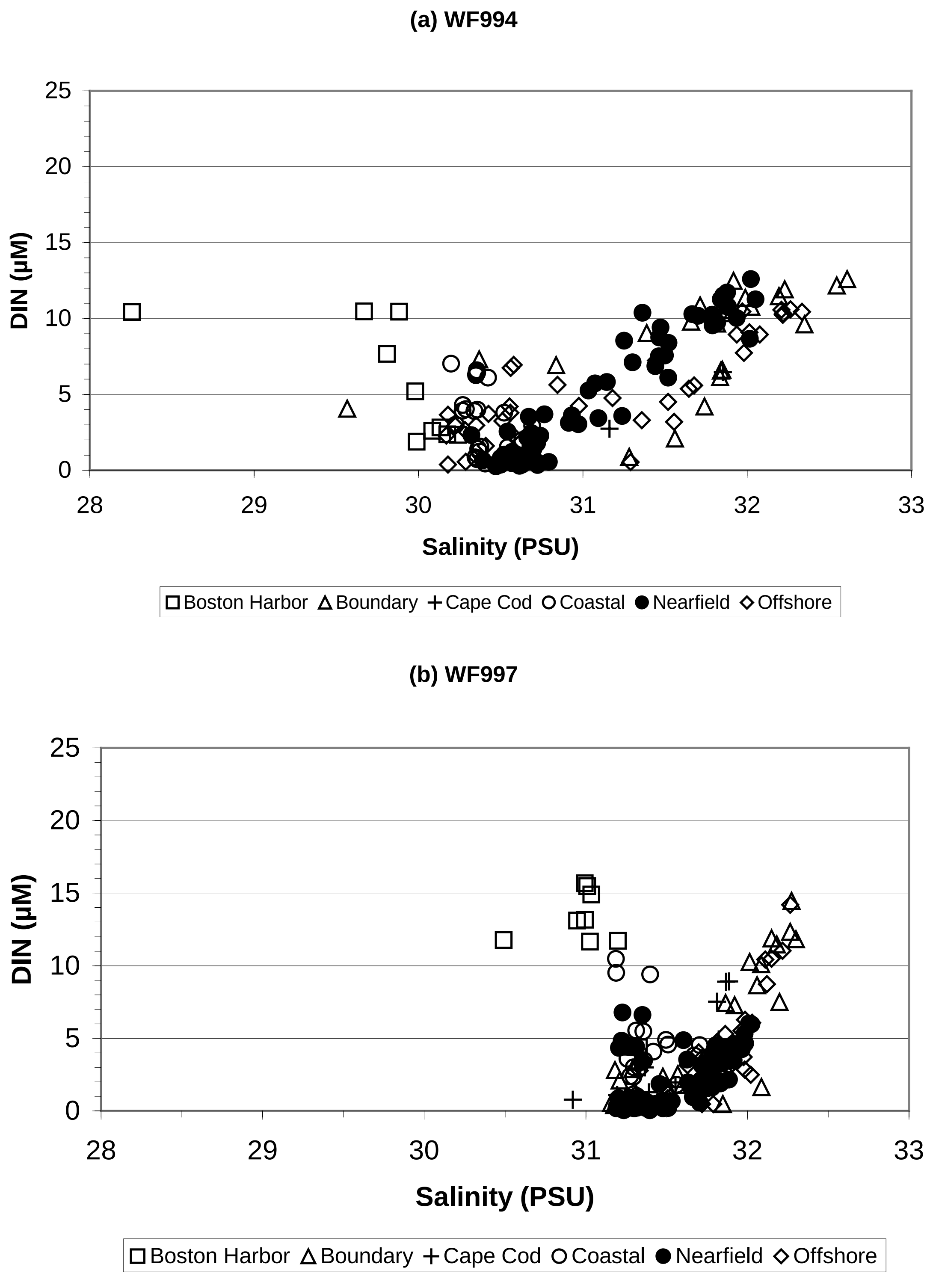


Figure 4-30. DIN vs. Salinity for All Depths during Farfield Surveys WF994 and WF997

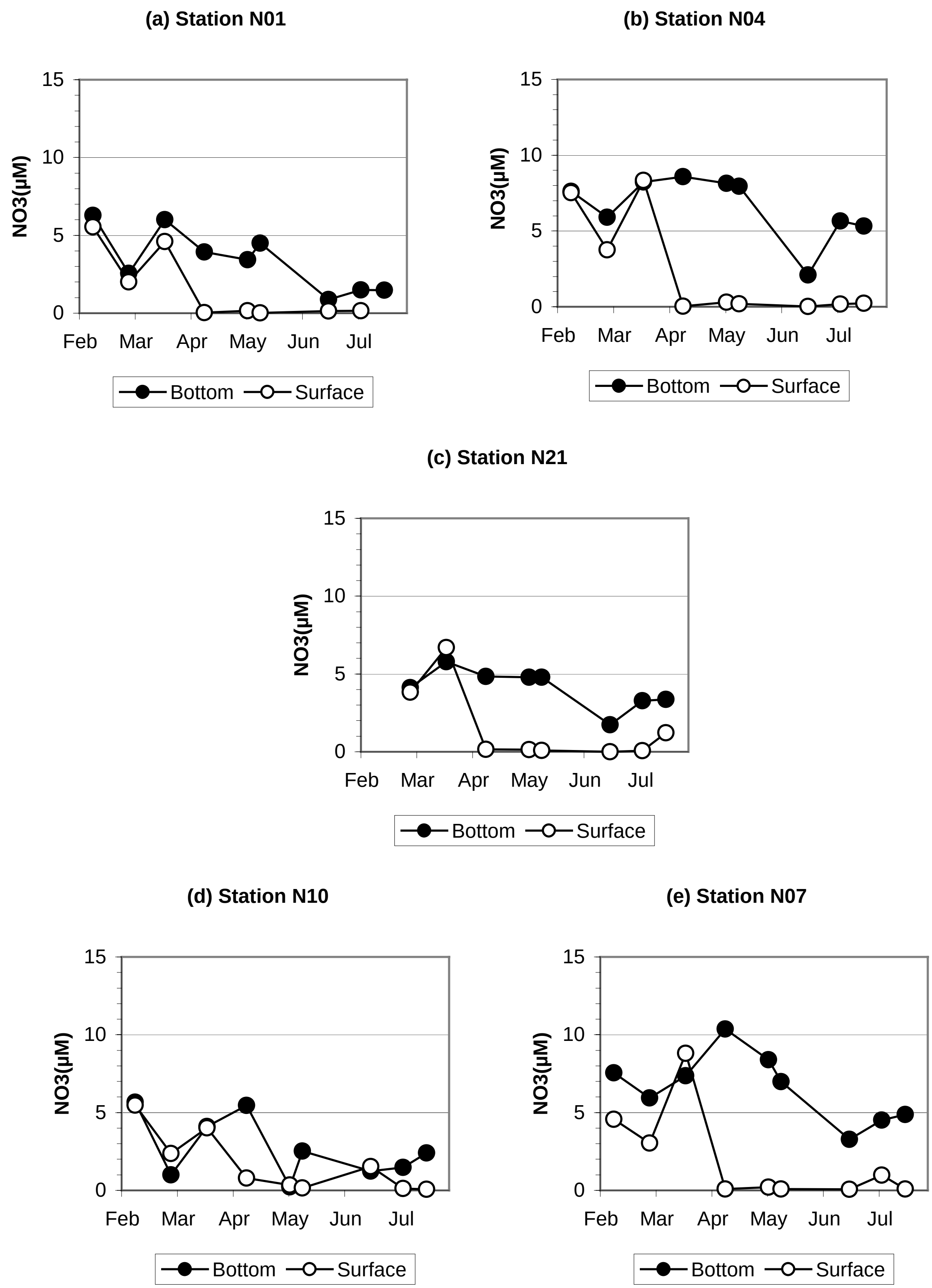


Figure 4-31. Time-Series of Surface and Bottom Water Nitrate Concentration in Five Nearfield Stations

Note: The arrangement of the figures on this page mimic the relative positions of the stations.

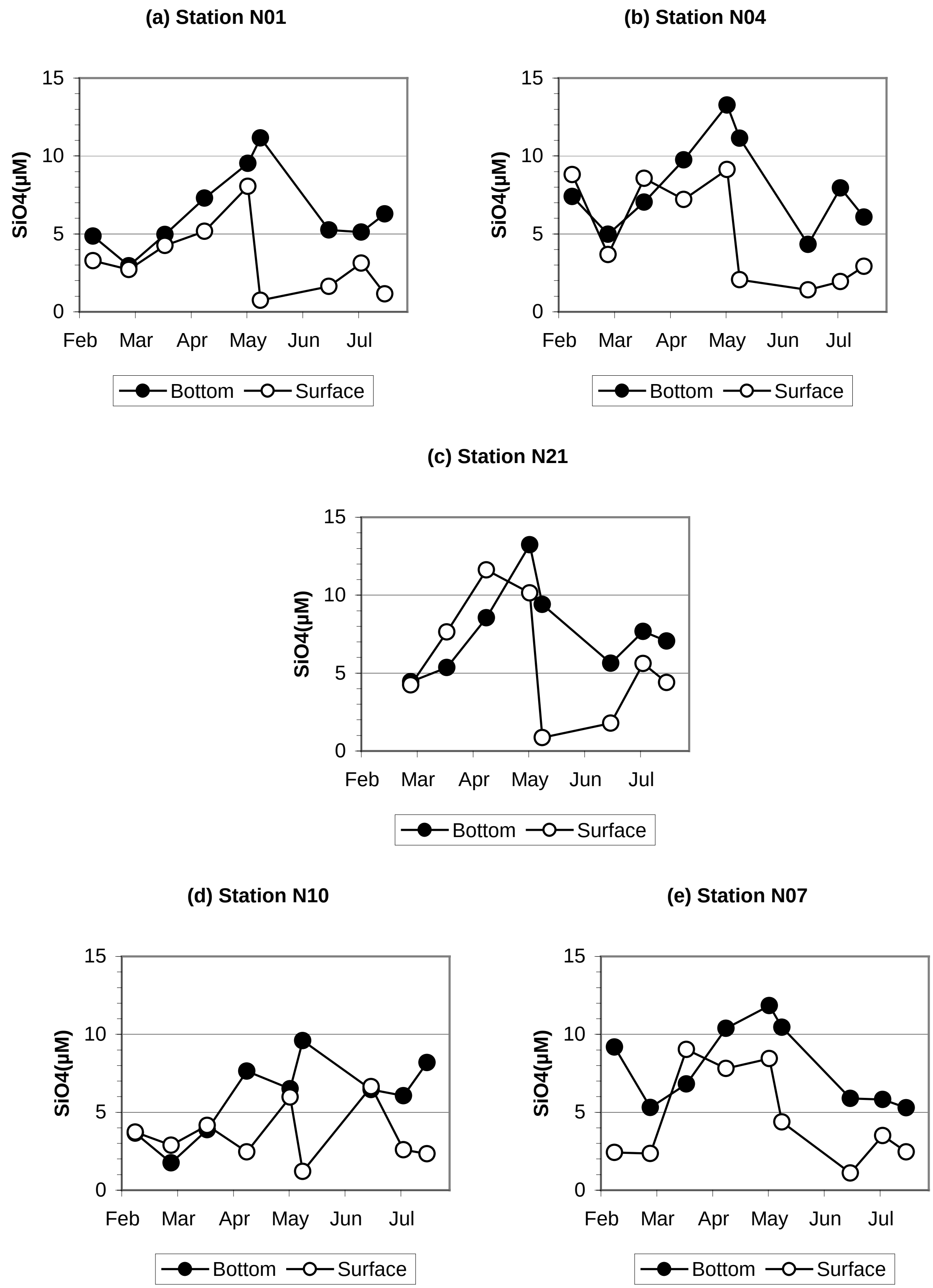


Figure 4-32. Time-Series of Surface and Bottom Water Silicate Concentration in Five Nearfield Stations

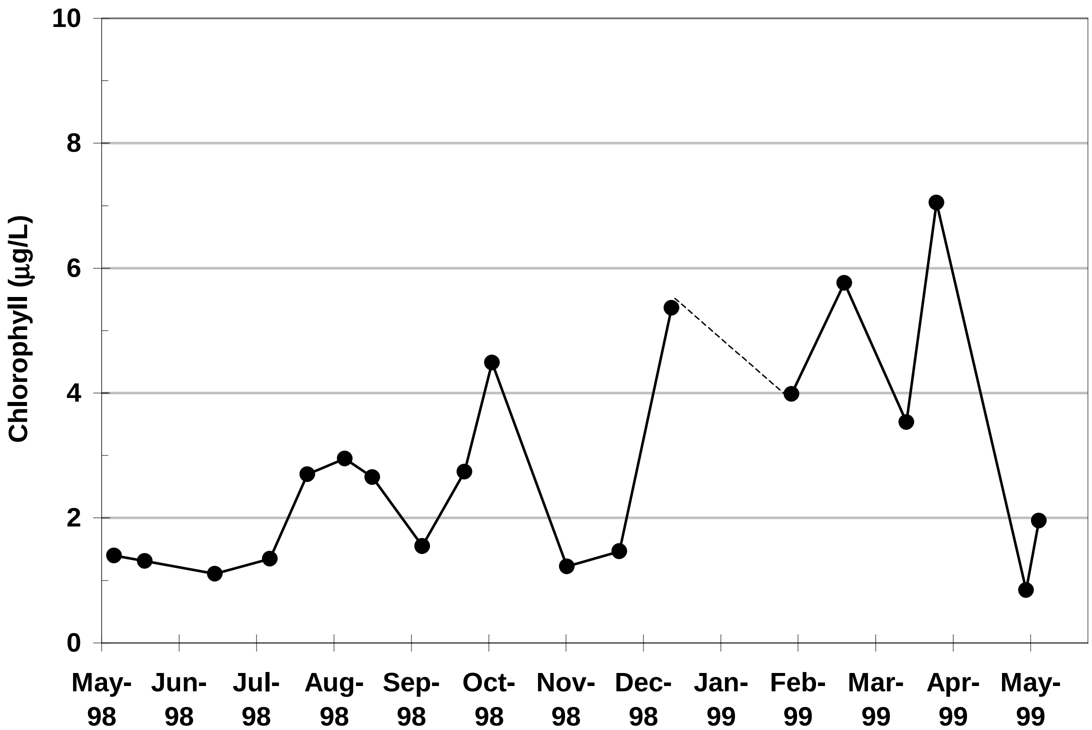


Figure 4-33. Average Nearfield Chlorophyll a Data May 1998 through May 1999

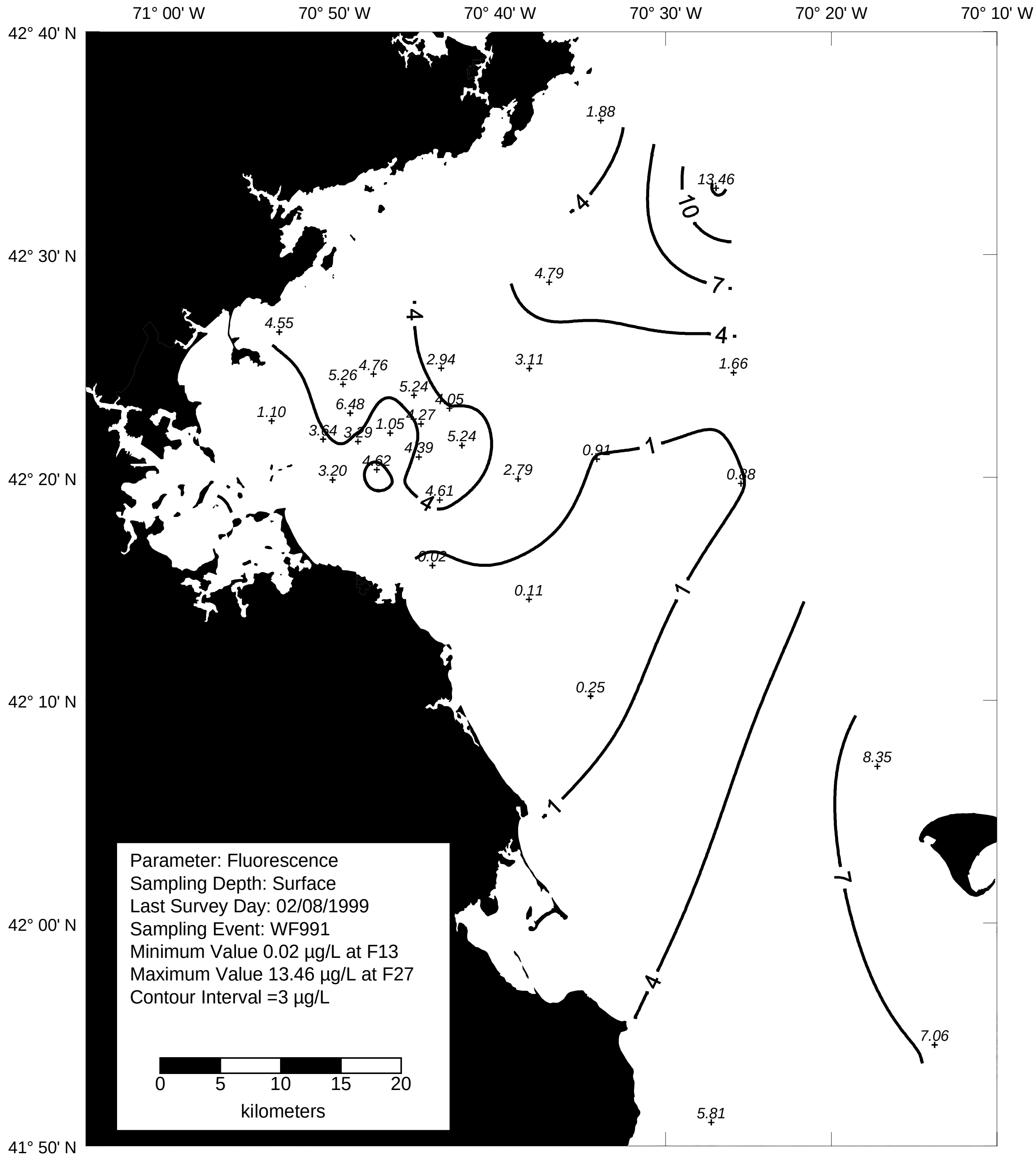


Figure 4-34. Fluorescence Surface Contour Plot for Farfield Survey WF991 (Feb 99)

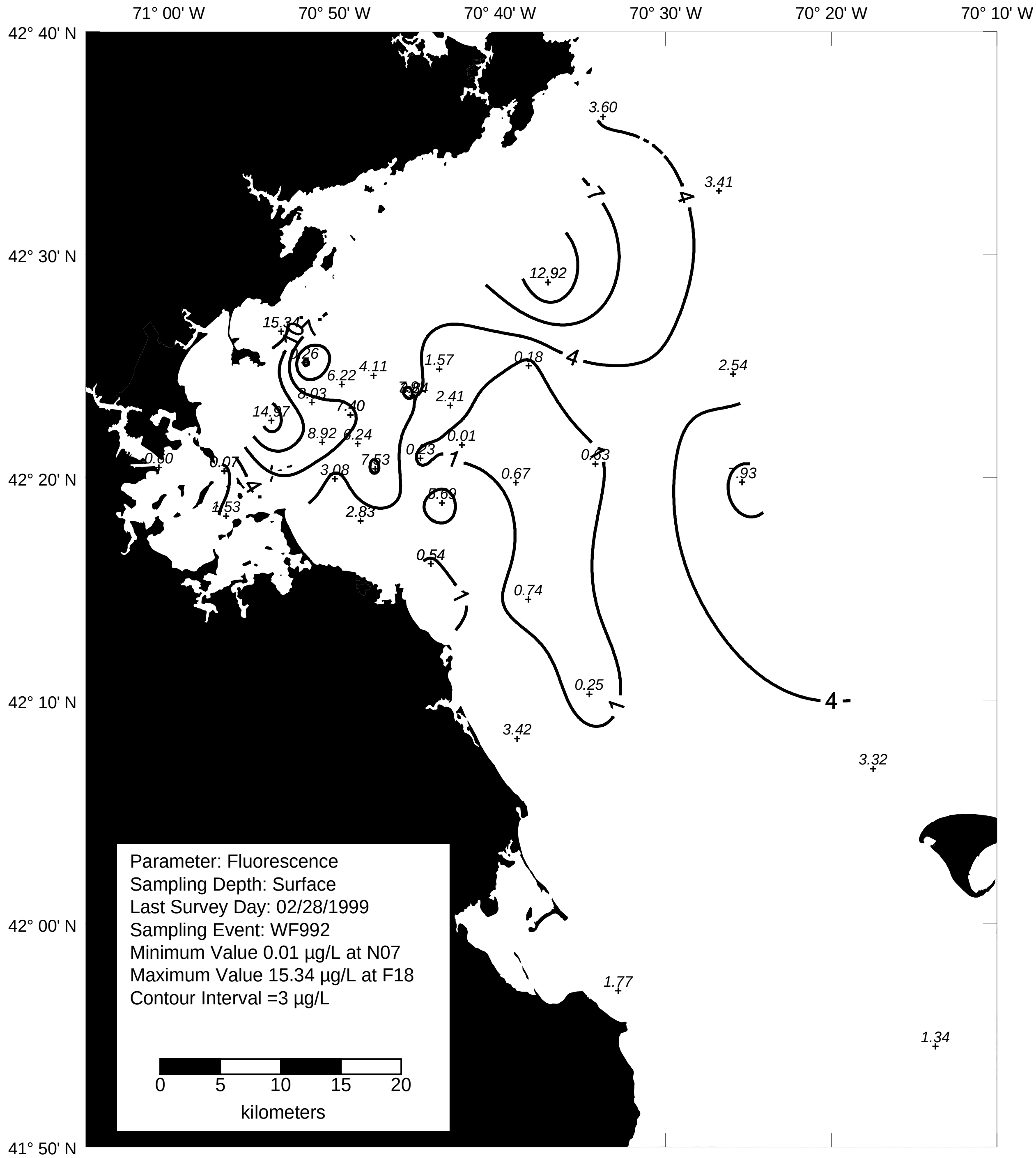


Figure 4-35. Fluorescence Surface Contour Plot for Farfield Survey WF992 (Feb 99)

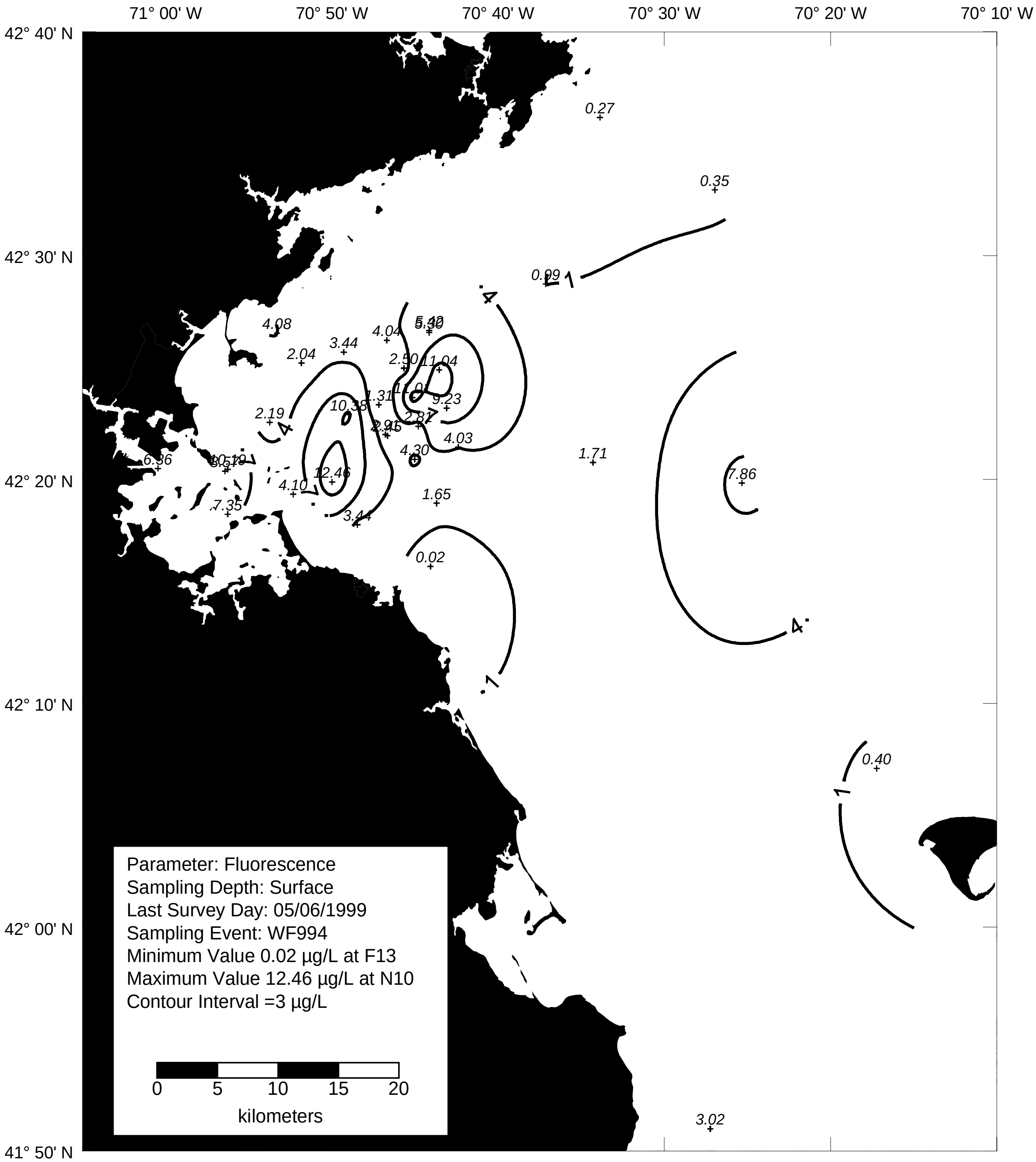


Figure 4-36. Fluorescence Surface Contour Plot for Farfield Survey WF994 (Apr 99)

Note: see Figure 4-5 for sample collection information.

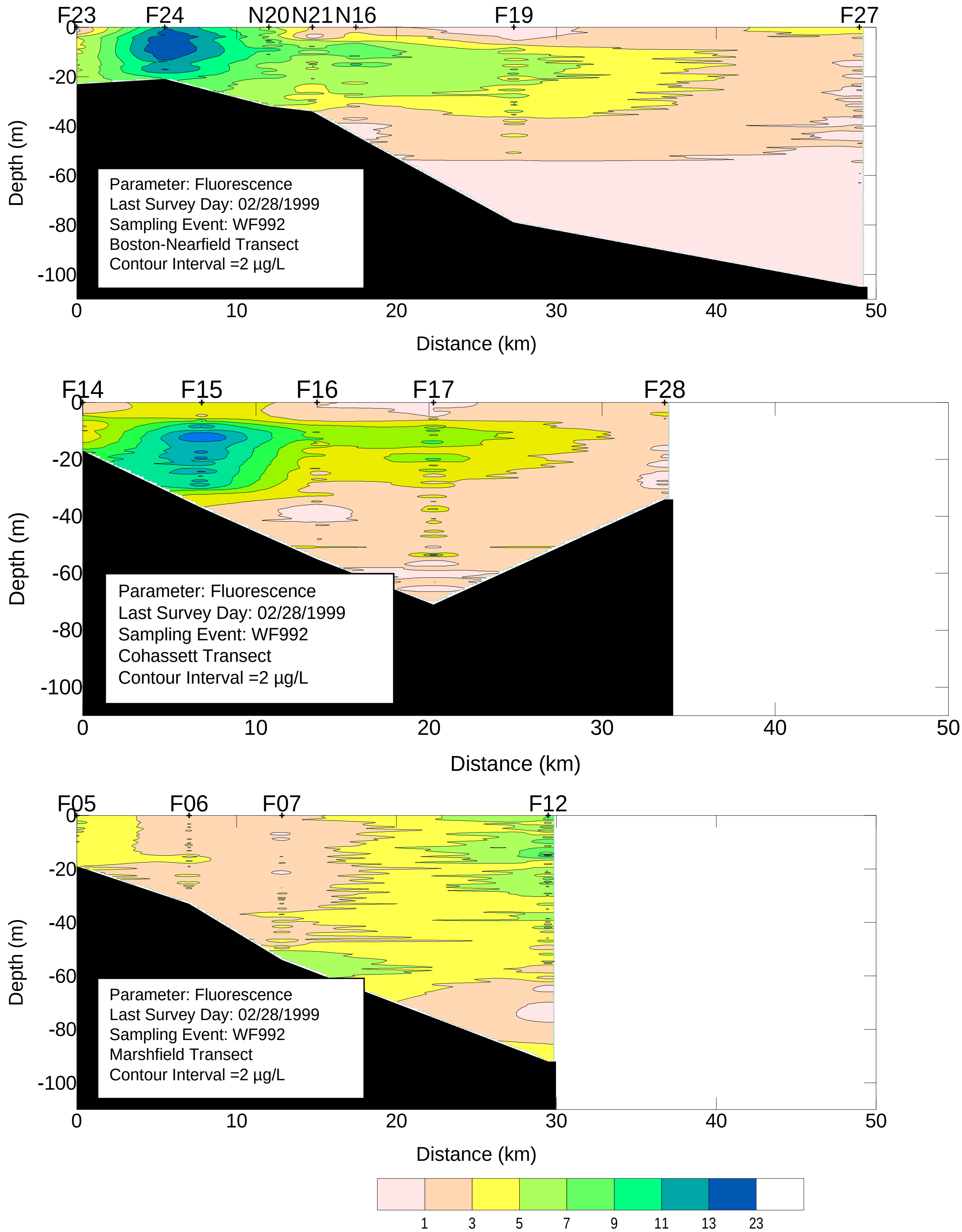


Figure 4-37. Fluorescence Vertical Transect Plots for Farfield Survey WF992 (Feb 99)

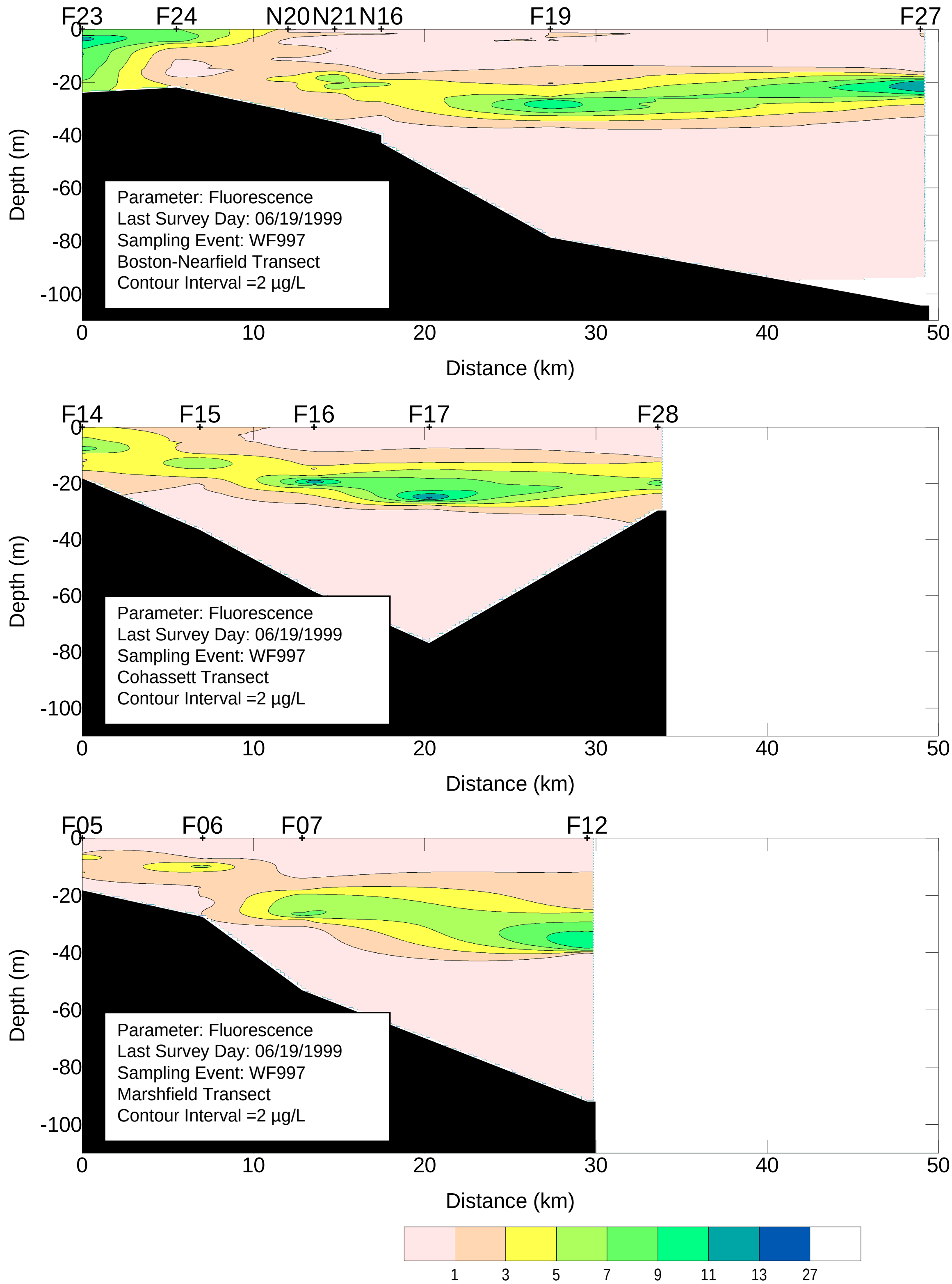


Figure 4-38. Fluorescence Vertical Transect Plots for Farfield Survey WF997 (Jun 99)

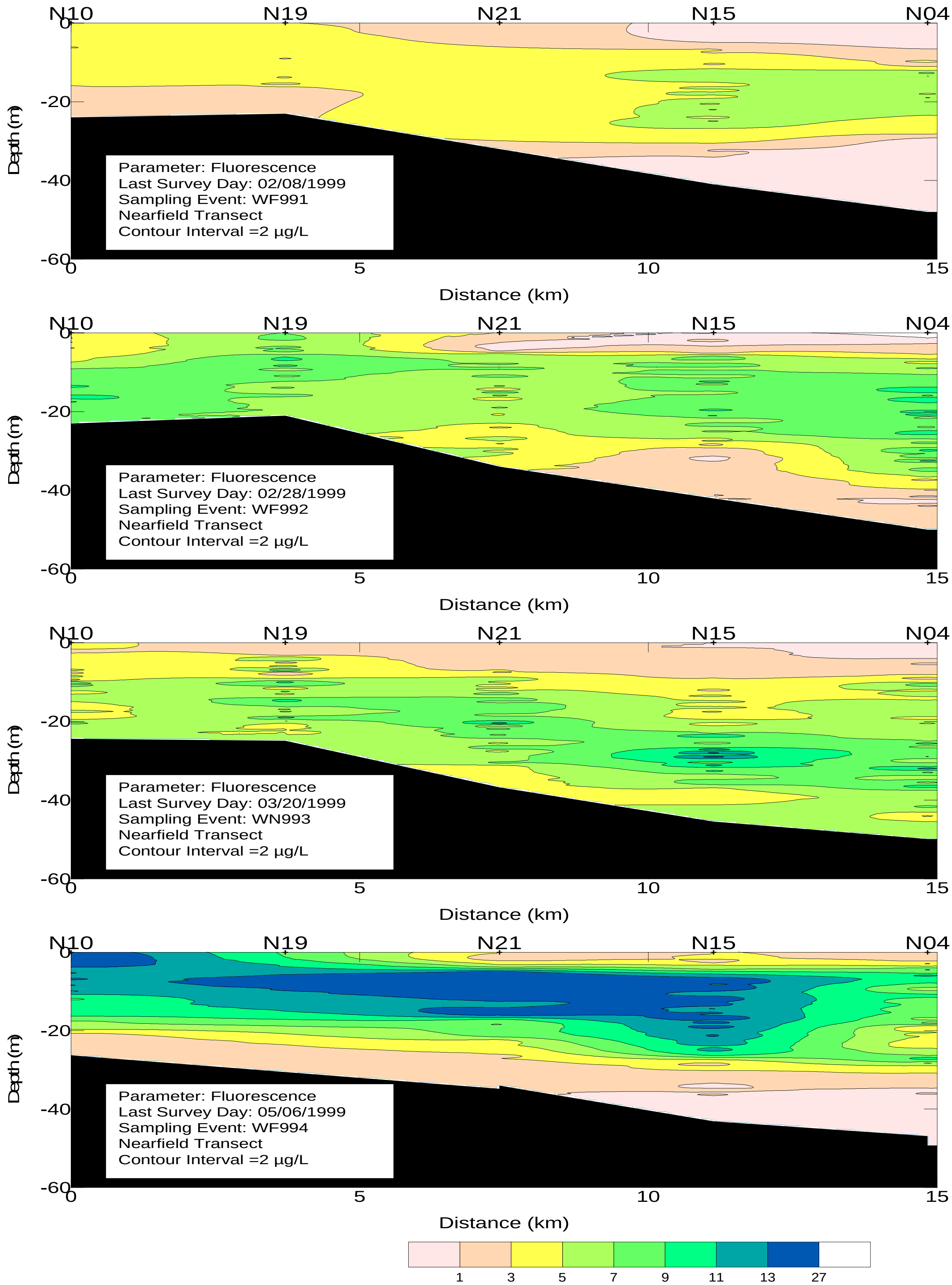


Figure 4-39. Fluorescence Vertical Nearfield Transect Plots for Surveys WF991 through WF994

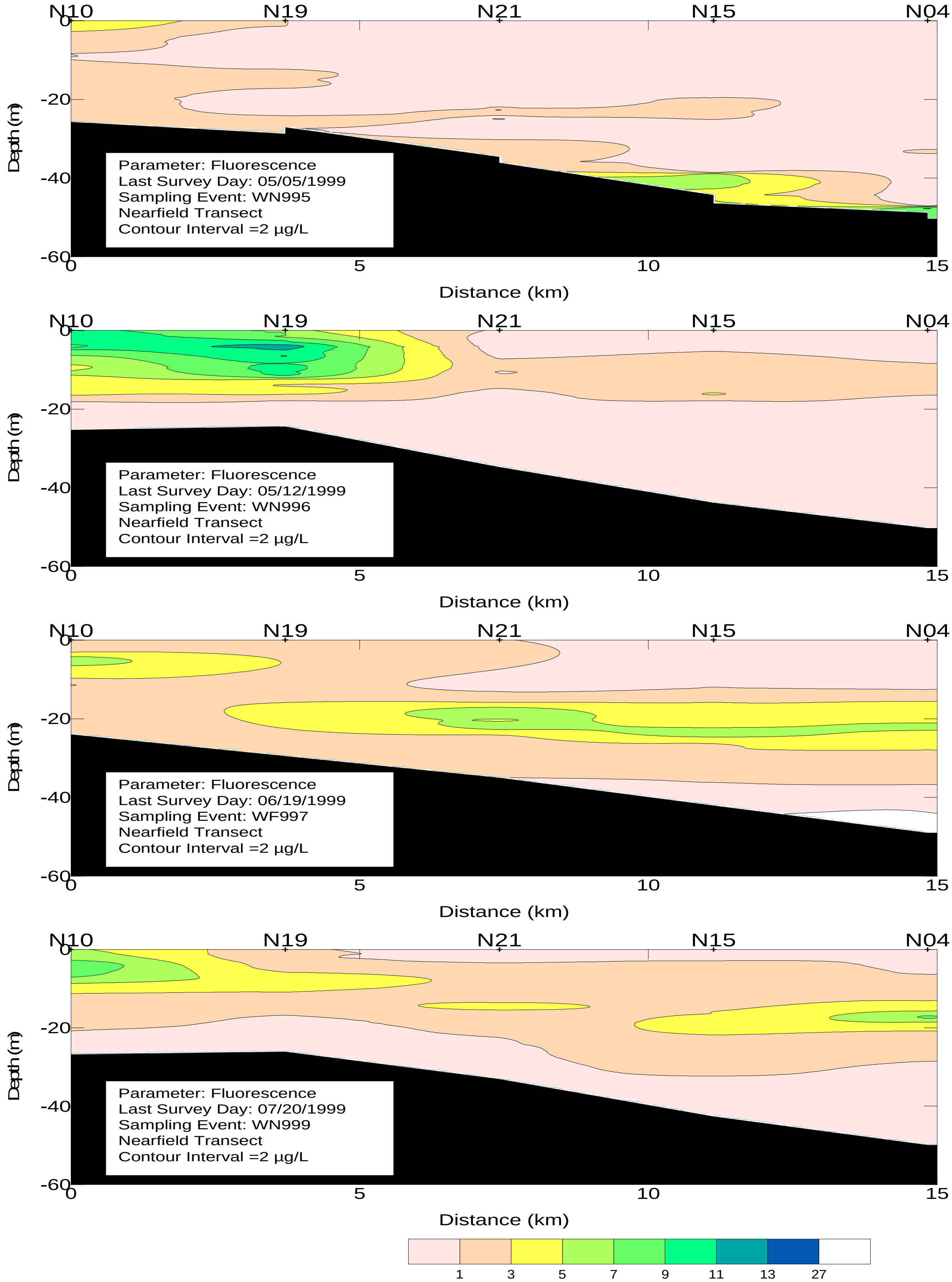


Figure 4-40. Fluorescence Vertical Nearfield Transect Plots for Surveys WN995 through WF997, and WN999

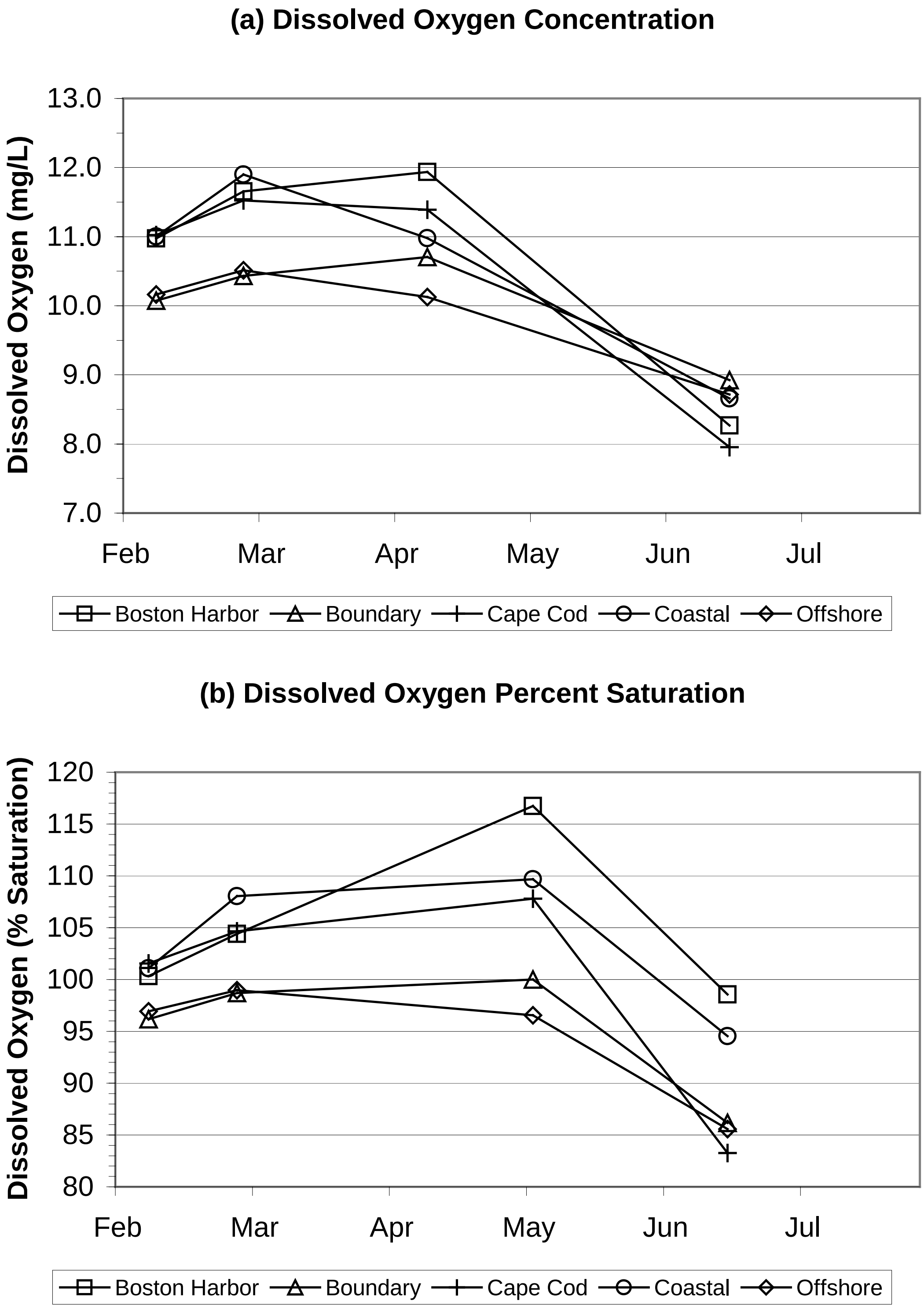


Figure 4-41. Time-Series of Bottom Water Average DO Concentration and Percentage Saturation in the Farfield

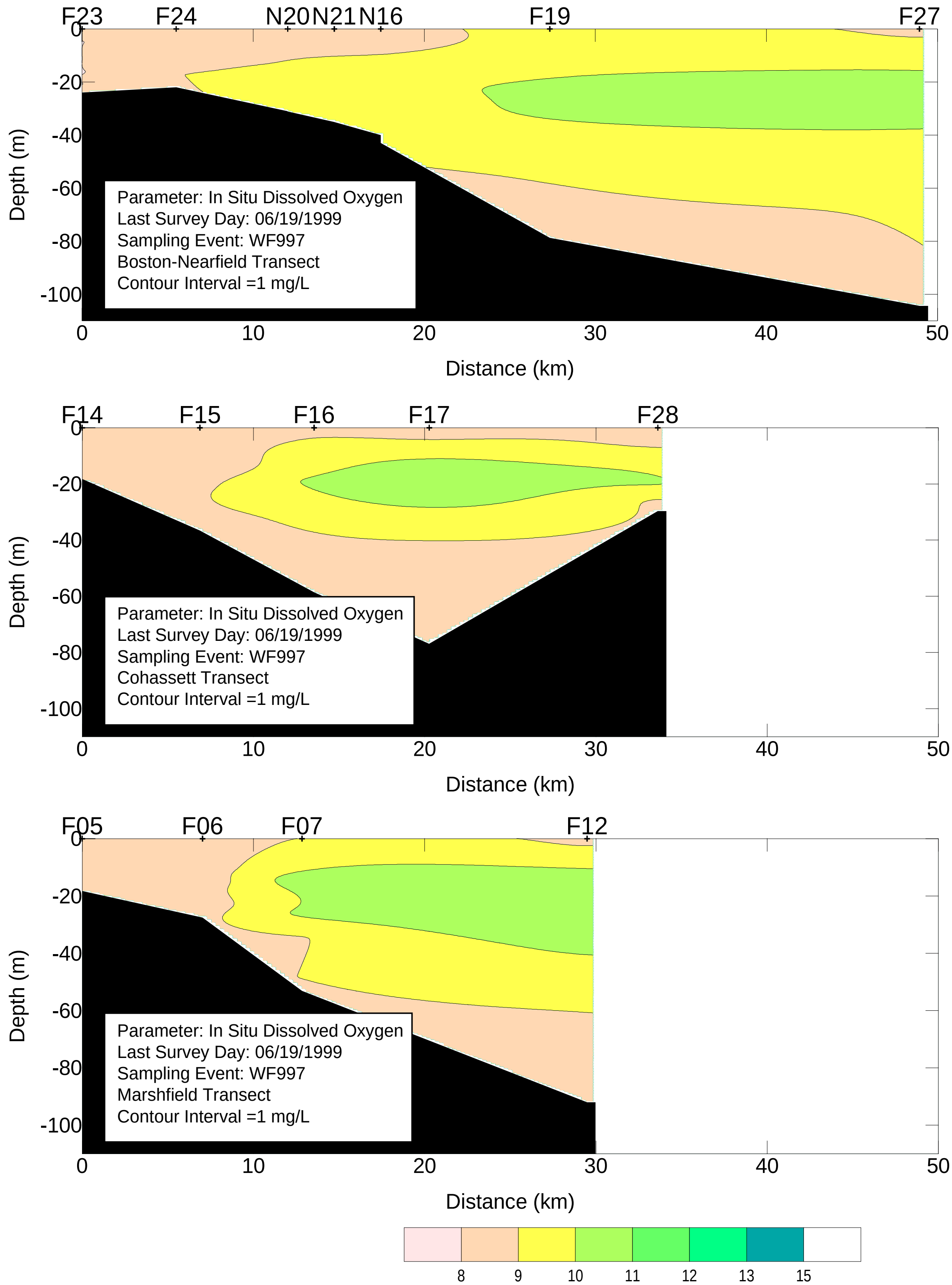
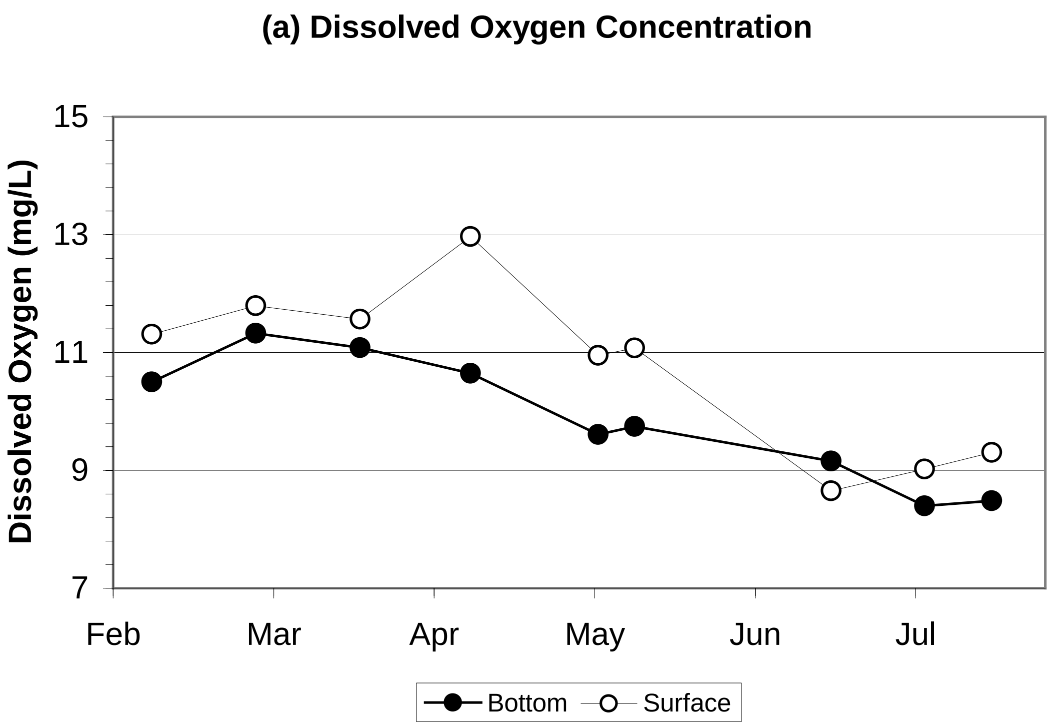


Figure 4-42. Dissolved Oxygen Vertical Transects for Survey WF997 (Jun 99)



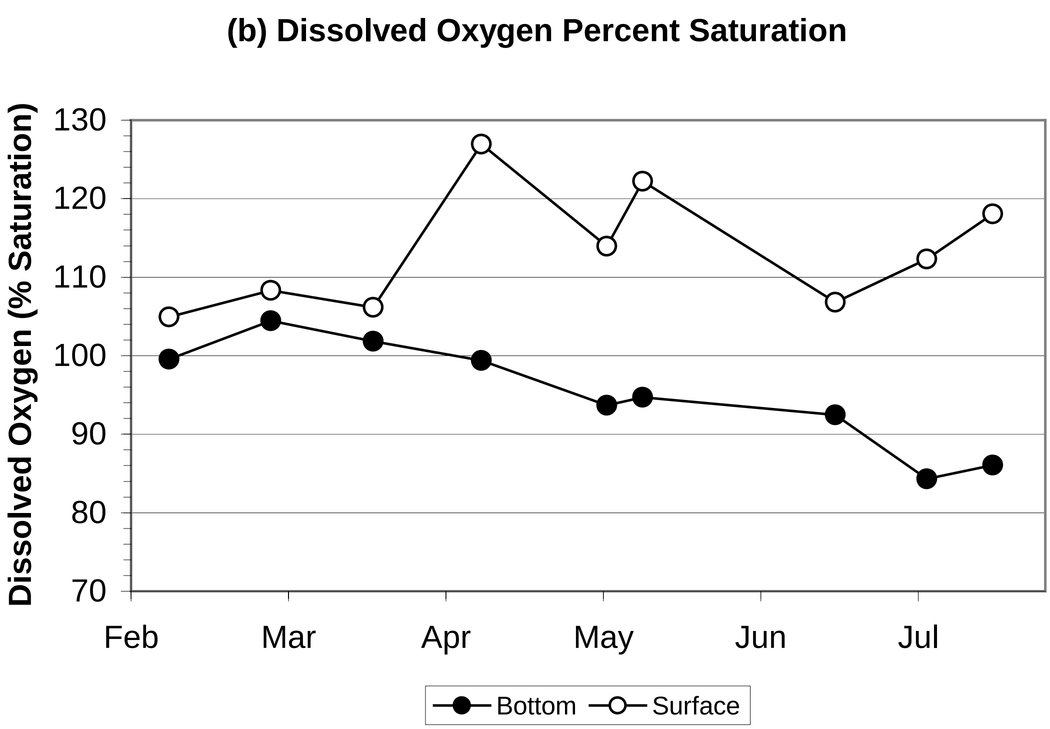


Figure 4-43. Time-Series of Bottom and Surface Average DO Concentration and Percentage Saturation in the Nearfield

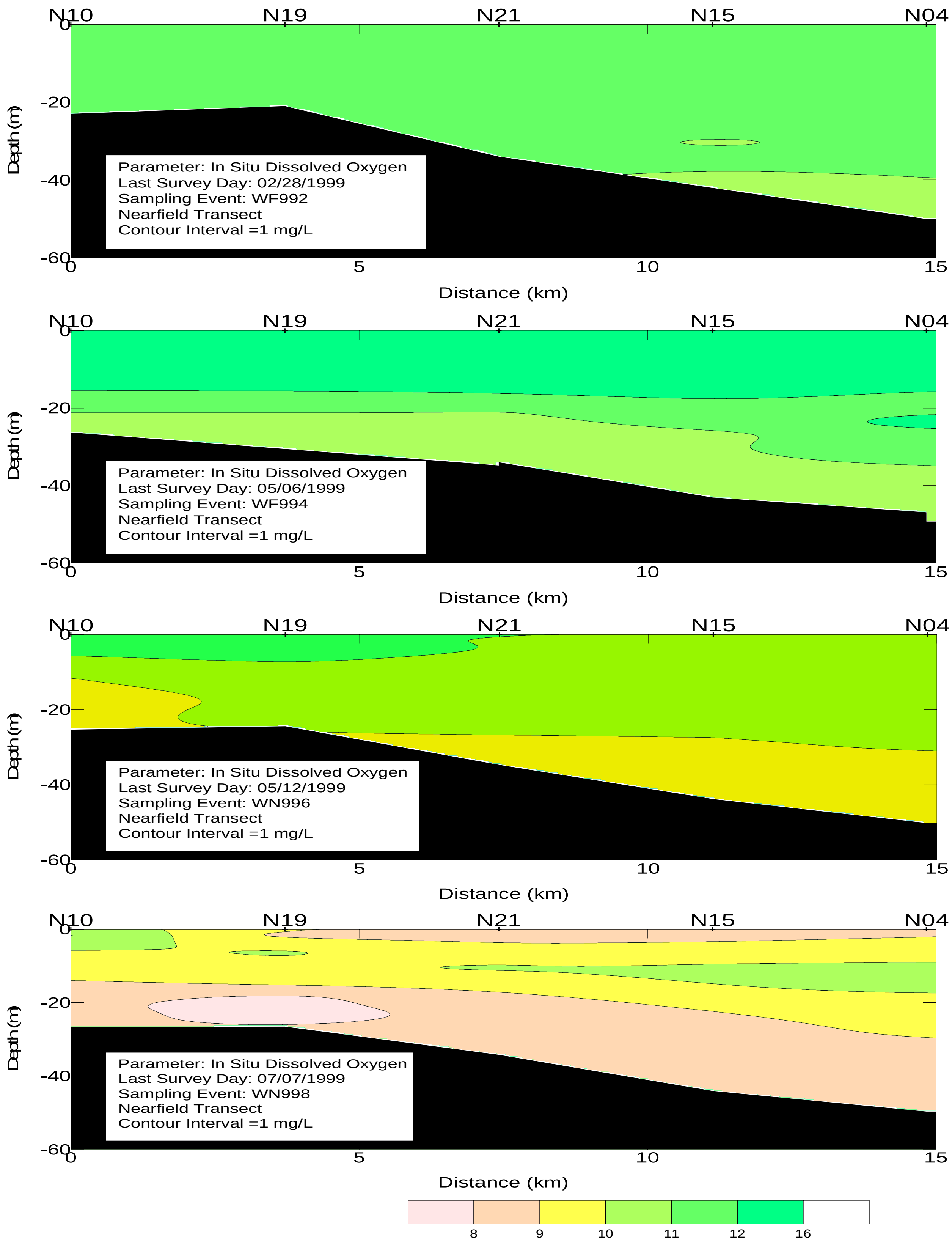


Figure 4-44. Dissolved Oxygen Vertical Nearfield Transects for Surveys WF992, WF994, WN996, and WN998

5.0 PRODUCTIVITY, RESPIRATION, AND PLANKTON RESULTS

5.1 Productivity

Primary production measurements were taken at two nearfield stations (N04, N18) and one farfield station (F23) near the entrance of Boston Harbor. All three stations were sampled on February 7, 1999 (WF991), February 27, 1999 (WF992), April 7, 1999 (WF994) and June 19, 1999 (WF997). N04 and N18 were additionally sampled on March 30, 1999 (WN993), April 29, 1999 (WN995), May 12, 1999 (WN996), July 7, 1999 (WN998), and July 20, 1999 (WN999). Samples were collected at five depths throughout the euphotic zone. Production was determined by measuring ^{14}C at varying light intensities as summarized below and in Appendix A.

In addition to samples collected from the water column, productivity calculations also utilized light attenuation data from a CTD-mounted 4π sensor, and incident light time-series data from a 2π irradiance sensor located on Deer Island, MA. After collection of the productivity samples, they were returned to the Marine Ecosystems Research Laboratory (MERL) in Rhode Island and incubated in temperature controlled incubators. The resulting photosynthesis versus light intensity (P-I) curves (Figure 5-1 and comprehensively in Appendix E) were used, in combination with light attenuation and incident light information, to determine hourly production at 15-min intervals throughout the day for each sampling depth.

For this semi-annual report, areal production (mg C m^{-2} d^{-1}) and chlorophyll-specific areal production (mgC mg Chl^{-1} d^{-1}) are presented (Figures 5-2 and 5-3). Areal productions are determined by integrating measured productivity (and chlorophyll-specific productivity) over the depth interval. Chlorophyll-specific productivity for each depth was first determined by normalizing productivity by measured chlorophyll *a*. Productivity and chlorophyll-specific productivity for each depth are also presented as contour plots (Figures 5-4, 5-5, 5-6 and 5-7).

5.1.1 Areal Production

Areal production at the nearfield stations (N04, N18) was similar throughout the semi-annual sampling period (February 7 - July 20, 1999) (Figure 5-2). Areal production at the two sites was relatively high (> 700 mg C m^{-2} d^{-1}) during the initial cruise on February 7, 1999 (WF991). Values increased at both sites to major production peaks by February 27, 1999 (WF992), decreased somewhat during the third cruise (WN993) then increased again to a second peak on April 7, 1999 (WF994). At both stations the timing and extent of the blooms in production were similar. The dominant bloom at station N04 occurred on February 27, 1999 (WF992) with a peak production of 2147 mg C m^{-2} d^{-1}. Station N18 did not reach its maximum value at this time but was characterized by an obvious peak in production (> 1500 mg $Cm^{-2}d^{-1}$). The situation was reversed for the second production peak on April 7, 1999. Areal production reached ~1650 mg C m^{-2} d^{-1} at station N04 while the peak production for N18 of 2176 mg C m^{-2} d^{-1} was reached at this time. Areal production declined at both stations N04 and N18 on April 29, 1999 (WN995). The minimum observed production (~250 mg C m^{-2} d^{-1}) for the nearfield sites was recorded at station N18 during this sampling cruise. Production increased to greater than 800 mg C m^{-2} d^{-1} at stations N04 and N18 by May (WN996) and remained somewhat elevated (~550 - 1300 mg C m^{-2} d^{-1}) throughout July (WF997 to WN999). The patterns observed at the nearfield sites were consistent with patterns seen in chlorophyll distributions (Section 4.2.2).

Boston Harbor (station F23) displayed a different productivity pattern in comparison with the nearfield sites. At the Boston Harbor productivity/respiration station (F23), areal production was relatively low (~250 mg C m^{-2} d^{-1}) during the initial cruise (February 7, 1999). Areal production increased somewhat to ~800 mg C m^{-2} d^{-1} by February 27 (WF992). Areal production reached a maximal value of 2915 mg C m^{-2} d^{-1} at station F23 during the April survey (WF994) and remained at a similarly high value

(2851 mg C m^{-2} d^{-1}) during the June survey (WF997). The production data are in agreement with the chlorophyll data, which indicated that a phytoplankton bloom occurred during this period.

In contrast to 1998, areal production in 1999 followed patterns typically observed in prior years. Distinct winter-spring phytoplankton blooms were observed at both nearfield stations during the sampling period (Figure 5-2). In general, nearfield stations are characterized by the occurrence of a winter-spring bloom. The winter-spring blooms observed at nearfield stations in 1995-1997 generally reached values of 1000 to 4000 mg C m^{-2} d^{-1}, with blooms typically lasting 2-3 months. The bloom in 1999 reached peak values of >2000 mg C m^{-2} d^{-1} and lasted from February through April and represents a return to expected patterns following the somewhat unusual cycle observed last year. The absence of a winter-spring phytoplankton bloom during 1998, a major change in the seasonal productivity pattern relative to other years for the nearfield region was not repeated in 1999.

In general, the Boston Harbor site (station F23) exhibits a gradual pattern of increasing areal production from winter through summer rather than the distinct winter-spring peaks observed at the nearfield sites. In 1999 the pattern for station F23 conformed to this description. Production values increased gradually from February through June (Figure 5-2). During 1995-1997, peak areal productions at station F23 ranged from 2000 to 5000 mg C m^{-2} d^{-1} in June-July. The peak areal productions observed in April-June 1999 (2851 - 2914 mg C m^{-2} d^{-1}) at station F23 were similar to peak values observed in previous years. The productivity cycle at station F23 in 1999, which was aberrant in 1998, represented a return to more typical conditions.

5.1.2 Chlorophyll-Specific Production

Chlorophyll-specific areal production was very similar at both nearfield sites (stations N04 and N18) over time (Figure 5-3). Chlorophyll-specific areal production was relatively low at the start of the sampling period then gradually increased at both stations until the seasonal maxima were reached during the mid-May survey (WN996). Seasonal maxima were greater than 1100 mg C mg chl a^{-1} d^{-1}. Following these peak values chlorophyll-specific areal production decreased to less than 450 mg C mg Chl a^{-1} d^{-1} in June 1999 (WF997) then gradually climbed till the end of the sampling period. By comparison chlorophyll-specific rates at the Harbor station F23 did not exceed 300 mg C mg Chl a^{-1} d^{-1} throughout the sampling cycle (Figure 5-3).

Chlorophyll-specific production is an approximate measure for the efficiency of production and frequently reflects nutrient conditions at the sampling sites. The distribution of chlorophyll-specific production indicates that the efficiency of production was high relative to the amount of biomass present at the nearfield stations. At both stations N04 and N18 the peak chlorophyll-specific production occurred well after the cessation of the winter-spring production peak. By contrast, efficiency of production was low at the Harbor site relative to biomass availability.

5.1.3 Vertical Trends in Production

The spatial and temporal distribution of production and chlorophyll-specific production on a volumetric basis were summarized by showing contoured production over the sampling period (Figures 5-4 to 5-7). Chlorophyll-specific productions (daily production normalized to chlorophyll concentration at each depth) were calculated to compare production with chlorophyll concentrations. Chlorophyll-specific production can be used as an indicator of the optimal conditions necessary for photosynthesis.

The peaks in areal productivity reported during late February and early April at station N04 were concentrated in the surface water (Figure 5-4). At station N18, the initial productivity peak was also confined to surface waters (<5 m) but the secondary bloom in early April was distributed throughout the water column (Figure 5-5). At the two nearfield stations, surface productions tended to decrease following the spring peak values but increased again in July. For both stations N04 an N18, the highest production values observed (>200 mg C m^{-3} d^{-1}) occurred at the surface on February 27, 1999. Peak production values tended to be correlated with the occurrence of the highest chlorophyll *a* measurements.

A subsurface (10-20 m) productivity maximum was measured at station N18 on June 19, 1999 (WF997). A subsurface production maximum was also observed at station N04 during the June 19, 1999 survey, however the peak depth of occurrence was observed at ~ 12 m (Figures 5-4 and 5-5). Subsurface productivity maxima tended to occur at both station N04 and N18 during June and July 1999. The productivity pattern at specified depths observed in 1999 was similar to that observed in prior years. At station N04 productivity >10 mg m^{-3} d^{-1} was rarely observed at depths >20 m. At station N18 productivity as high as 40 mg C m^{-3} d^{-1} was recorded from depths of 20 m with values from 10-30 mg C m^{-3} d^{-1} frequently observed here. Productivity in the Harbor was largely restricted to the upper 10 m of the water column.

Chlorophyll-specific productions at N04 and N18 were also concentrated in the upper portions of the water column (Figures 5-6 and 5-7). Peak chlorophyll-specific productions occurred early in the sampling season at station N04 and somewhat later at station N18. The efficiency of photosynthesis decreased slightly as the season progressed. When the efficiency of photosynthesis is high but not reflected in higher phytoplankton biomass (measured as total chlorophyll *a*) it suggest that other processes (such as predation by zooplankton) are important in controlling the patterns observed.

5.2 Respiration

Respiration measurements were made at the same nearfield (N04, N18) and farfield (F23) stations as productivity and at an additional station in Stellwagen Basin (F19). All four stations were sampled during each of the combined farfield/nearfield surveys and stations N04 and N18 were also sampled during the five nearfield surveys. Respiration samples were collected from three depths (surface, mid-depth, and bottom) and were incubated in the dark at *in situ* temperatures for 8±1 days.

Both respiration (in units of $\mu MO_2\,hr^{-1}$) and carbon-specific respiration ($\mu MO_2\,\mu MC^{-1}\,hr^{-1}$) rates are presented in the following sections. Carbon-specific respiration was calculated by normalizing respiration rates to the coincident particulate organic carbon (POC) concentrations. Carbon-specific respiration rates provide a relative indication of the biological availability (labile) of the particulate organic material for microbial degradation.

5.2.1 Water Column Respiration

Due to electrical problems with the incubators in February (WF991), there are only three sets of respiration data for the farfield stations (F23 and F19). The data for the April survey (WF994) have been qualified in the database as suspect because incubator temperatures increased to ~10°C for 24 to 48 hours. The *in situ* temperatures for the WF994 respiration samples were 5.0 ± 2.0 °C. The increase in incubator temperature to 10 °C for a short time period probably had a negligible effect on the respiration rates for these samples and the data have been included in this report. The evaluations of the temporal trends are focused on the nearfield area where data are available over the whole February to July time period.

During the surveys conducted in February (WF992) and March (WN993), respiration rates were generally low in the nearfield area (<0.10 μMO_2 hr^{-1}) and comparable over depth (Figure 5-8). By April (WF994), respiration rates had increased 2 to 4-fold in the nearfield (0.1 to 0.4 μMO_2 hr^{-1}) and similar increases were observed at Harbor station F23 and less significant increases at offshore station F19. Respiration rates reached a maximum for the time period in the nearfield in early May (WN995) with rates at station N18 ranging from 0.5 to 0.8 μMO_2 hr^{-1} with the highest rate observed in the mid-depth waters. Respiration rates were lower at station N04, but had continued to increase from the levels observed during the April survey (WF994). The increase in respiration rates in April was coincident with the peak production values observed for the winter-spring bloom. By early May, the senescent bloom may have fueled the high respiration rates that were observed as the readily available labile organic material was degraded. Respiration rates during this time period were generally higher in the surface and mid-depth waters where the temperatures were warmer and higher rates of primary production were observed.

By mid-May (WN996), respiration rates had decreased to 0.2 to 0.35 μMO_2 hr^{-1} in the nearfield and they continued to decrease into June reaching rates of $\leq$ 0.10 μMO_2 hr^{-1}. The only exception was an increase in respiration in the surface water at station N04 to ~0.65 μMO_2 hr^{-1}, which was coincident with an increase in surface water respiration at offshore station F19 (0.20 μMO_2 hr^{-1}). In the Harbor, respiration rates had decreased from the maximum levels observed in April, but were generally higher than those observed at the three other stations. Respiration rates remained relatively low (<0.20 μMO_2 hr^{-1}) during the July surveys with the highest values being observed in the surface waters at station N18.

5.2.2 Carbon-Specific Respiration

Carbon-specific respiration accounts for the effect of variations in the size of the particulate organic carbon (POC) pool have on respiration. Differences in carbon-specific respiration result from variations in the quality of the available particulate organic material or from environmental conditions such as temperature. Particulate organic material that is more easily degraded (more labile) will result in higher carbon-specific respiration. In general, newly produced organic material is the most labile. Water temperature is the main physical characteristic that controls the rate of microbial oxidation of organic material – the lower the temperature the lower the rate of oxidation. When stratified conditions exist, the productive, warmer surface and/or mid-depth waters usually exhibit higher carbon-specific respiration rates and bottom waters have lower carbon-specific respiration rates due to both lower water temperature and lower substrate quality due to the degradation of particulate organic material during sinking.

There was a general increase in POC concentrations from February to April and then a decrease from April to July (Figure 5-9), which is consistent with the pattern observed in chlorophyll over this time period. POC concentrations were relatively high (20-40 μMC) in the nearfield during the first two surveys and generally higher in the surface and mid-depth waters. By March (WN993), POC concentrations had decreased to ~20 μMC at the two nearfield stations (slightly higher in the surface water at station N18). POC concentrations at the Harbor station increased significantly during the month of February from ~30 μMC in early February (WF991) to 50-90 μMC in late February (WF992). The carbon-specific respiration rates were low (<0.005 μMO_2 μMC^{-1} hr^{-1}) at all three stations during this time period (Figure 5-10). This suggests that the very high POC concentrations that were measured at station F23 in late February were probably due to degraded or detrital material transported from the Harbor or other coastal areas rather than labile organic material.

In April (WF994), POC concentrations had increased at both nearfield stations to approximately 40-55 μMC (lower in the deeper bottom water at station N04). These elevated concentrations were coincident with high chlorophyll concentrations and high production rates. Nearfield carbon-specific respiration rates increased with the increasing availability of labile organic material in April, but did not reach maximum values until early May (WN995). At Harbor station F23, POC concentrations remained higher than the nearfield concentrations in April and into June (40-70 μMC), but carbon-specific respiration rates were low throughout this period $\leq$ 0.005 μMO_2 μMC^{-1} hr^{-1}.

POC concentrations decreased to ~20 μMC at the nearfield stations by early May (WN995) coincident with significant decreases in chlorophyll concentration and production rates due to the senescence of the winter-spring bloom. Carbon-specific respiration rates, however, increased considerably and reached maximum rates over the water column for this time period at station N18 (0.035-0.045 μMO_2 μMC^{-1} hr^{-1}). The increase in carbon-specific respiration rates at station N18 may have been due to the presence of a more labile pool of POC, but is more likely due to elevated concentrations of dissolved organic carbon, which reached a maximum (>400 μMC) during this period in early May.

The POC concentrations remained relatively low during the mid-May (WN996) and June (WF997) surveys at both nearfield stations. This was concomitant with lower carbon-specific respiration at station N18 and during the mid-May survey at station N04. In June, however, the carbon-specific respiration rate in the surface water at N04 reached a station maxima of 0.035 $\mu MO_2\,\mu MC^{-1}\,hr^{-1}$. POC concentrations varied from 10 to 50 µMC in the nearfield during the July surveys, but carbon-specific respiration remained low ($\leq$0.007 $\mu MO_2\,\mu MC^{-1}\,hr^{-1}$)

5.3 Plankton Results

Plankton samples were collected on each of the nine surveys conducted during this reporting period. Phytoplankton and zooplankton samples were collected at two stations during each nearfield survey and at 11 stations during the farfield surveys. During the first three farfield surveys of 1999 (WF991, WF992, and WF994), zooplankton samples were collected at two additional stations in Cape Cod Bay (F32 and F33). Phytoplankton samples included both whole-water and 20 µm-mesh screened samples, from the surface and subsurface chlorophyll maximum depths. Zooplankton samples were collected by vertical/oblique tows with 102 µm-mesh nets. Methods of sample collection and analyses are detailed in Albro *et al*. (1998).

In this section, the seasonal trends in plankton abundance and regional characteristics of the plankton assemblages are evaluated. Total abundance and relative abundance of major taxonomic group are presented for each phytoplankton and zooplankton community. Tables in the appendices provide data on cell densities and relative abundance for all dominant plankton species (>5% abundance): Appendix F – whole water phytoplankton, Appendix G – 20-µm screened phytoplankton, and Appendix H – zooplankton.

5.3.1 Phytoplankton

5.3.1.1 Seasonal Trends in Total Phytoplankton Abundance

Total phytoplankton abundances in nearfield whole water samples (surface and subsurface mid-depths) were variable from February through May (Table 5-1). Total abundances at the surface varied between approximately 0.5 –2.0 x 10^6 cells l^{-1} at station N18 (Figure 5-11a), station N16 (Figure 5-11b) and station N04 (Figure 5-11c). Total abundances at mid-depth were also <2 x 10^6 cells l^{-1} from February to May, with the exception of survey WF994 on April 11, when abundances at stations N18 and N04 reached 3 x 10^6 cells l^{-1} (Figure 5-12). Total phytoplankton abundance declined in the nearfield in June and July to levels < 1.0 x 10^6 cells l^{-1} (Figures 5-11 and 5-12).

Total phytoplankton abundance in farfield whole water samples (surface and subsurface mid-depths) showed similar low abundances in February with levels generally < 1 x 10^6 cells l^{-1} during Survey WF991 (Figure 5-13), and values generally between 1-2 x 10^6 cells l^{-1} during Survey WF992 (Figure 5-14). By April to early May (Survey WF994) abundances still had not increased above the 1-2 x 10^6 cells l^{-1} level, except at 4 mid-depth stations (F01, F31, N04 and N18) where abundances were around 3 x 10^6 cells l^{-1} in comparison to the 2 x 10^6 cells l^{-1} or less at the other stations (Figure 5-15). By June (Survey WF997) phytoplankton abundance had actually declined, with levels < 1.6 x 10^6 cells l^{-1} at all stations, and levels < 1.0 x 10^6 cells l^{-1} at most stations (Figure 5-16).

Total abundances of dinoflagellates, silicoflagellates and protozoans in 20 µm-mesh-screened water samples were considerably lower than those recorded for total phytoplankton in whole-water samples, due to the screening technique which selects for larger, albeit rarer cells. Nonetheless, similar seasonal increases, though of different taxa, were recorded. Dinoflagellates in nearfield and farfield screened phytoplankton samples were generally at levels < 10^3 cells l^{-1} from February through early May, increasing to values of <2 to >3 x 10^3 cells l^{-1} from mid-May through July (Table 5-2). These increases in

screened phytoplankton abundance largely reflected a sustained bloom of the dinoflagellates *Ceratium fusus* and *Ceratium tripos*, and other species of this genus from February through July.
Perhaps the singular phytoplankton event of this period was the bloom of *Ceratium furca /C. tripos/* C. *longipes* which continued from the previous year, and exhibited sustained increases from February through July. The chlorophyll and production data indicated that a sustained winter-spring bloom occurred from February to April of 1999. This was not clearly represented in the phytoplankton abundance data. The winter-spring increases in *Ceratium* spp. and presence of chain forming *Chaetoceros* spp. in relatively high numbers may have led to this seeming discrepancy. Ancillary evidence (zooplankton tows and samples loaded with green algal material) suggests that these phytoplankton species may not have been adequately accounted for due to the methods employed in sampling the phytoplankton. Video plankton recorder data (Davis and Gallager, 2000) also suggests that the long chains of *Chaetoceros* may have been underestimated during this period. This discrepancy will be evaluated in more detail in the annual report for 1999.

Table 5-1. Nearfield and Farfield Averages and Ranges of Abundance (10^6 Cells L^{-1}) of Whole-Water Phytoplankton

Survey	Dates (1999)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF991	2/2 – 2/8	0.650	0.573 - 0.720	0.652	0.372 - 1.180
WF992	2/23 – 2/28	1.479	1.155 - 1.685	1.387	0.574 - 2.528
WN993	3/20	1.173	1.037 - 1.334	NA	NA
WF994	4/1 to 5/6*	2.016	0.831 - 3.029	1.565	0.424 - 3.420
WN995	5/5	0.460	0.327 - 0.628	NA	NA
WN996	5/12	1.294	1.056 - 1.498	NA	NA
WF997	6/14 – 6/19	0.383	0.180 - 0.776	0.935	0.275 - 1.630
WN998	7/7	0.556	0.345 - 0.954	NA	NA
WN999	7/20	0.393	0.178 - 0.811	NA	NA

NA- Data not available because the farfield stations were not sampled during this survey.

*Due to severe weather, the WF994 survey was completed over the course of six days in April and May – nearfield plankton samples were collected April 11th and farfield plankton samples were collected April 1, 6, 11, 26, and May 6.

Table 5-2. Nearfield and Farfield Average and Ranges of Abundance (Cells L^{-1}) for >20 μM-Screened Phytoplankton

Survey	Dates (1999)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF991	2/2 – 2/8	651	378 - 770	381	112 - 996
WF992	2/23 – 2/28	496	351 - 547	387	102 - 973
WN993	3/20	641	523 - 705	NA	NA
WF994	4/1 to 5/6*	341	84 - 605	398	93 - 1034
WN995	5/5	631	584 - 728	NA	NA
WN996	5/12	2387	1833 - 2950	NA	NA
WF997	6/14 – 6/19	2171	828 - 3517	2798	275 - 18735
WN998	7/7	2134	1541 - 2709	NA	NA
WN999	7/20	1874	740 - 3570	NA	NA

NA- Data not available because the farfield stations were not sampled during this survey.

*Due to severe weather, the WF994 survey was completed over the course of six days in April and May – nearfield plankton samples were collected April 11th and farfield plankton samples were collected April 1, 6, 11, 26, and May 6.

5.3.1.2 Nearfield Phytoplankton Community Structure

Whole-Water Phytoplankton – From February to April (WF991, WF992, WN993, WN994), nearfield whole-water phytoplankton assemblages from both depths were dominated by unidentified microflagellates and centric diatoms (Figures 5-11 and 5-12). These dominant taxa included several species of the centric diatom genus *Chaetoceros* (*C. socialis*, *C. debilis*, and an unidentified species of this genus), as well as pennate diatoms of the diatom genus *Pseudo-nitzschia* (during WF991). By May (WN995, WN996) the above-mentioned taxa, as well as cryptomonads, the centric diatom *Skeletonema costatum*, and the dinoflagellate *Prorocentrum minimum* were dominant.

In June and July (WF997, WN998) there was overwhelming numeric dominance by microflagellates, with additional subdominant contributions by centric diatoms of the genus *Thalassiosira*, and another unidentified centric, probably also a species of *Thalassiosira*, during Survey WN999 in late July.

Based on analyses since 1992, the whole-water phytoplankton assemblage in the nearfield was typical for the first half of the year during non-*Phaeocystis* years in terms of taxonomic composition. However it was atypical in the respect that there was no large spring phytoplankton bloom (in abundance), and unlike the previous year when there was a continuous increase in phytoplankton abundance from winter through early summer, phytoplankton abundance actually declined somewhat in summer.

Screened Phytoplankton - During early February (WF991) nearfield screened samples were dominated by the thecate dinoflagellates *Ceratium furca, C. tripos*, *Dinophysis norvegica*, *Prorocentrum minimum*, and various species of the genus *Protoperidinium*. These same taxa dominated during late February (WF992) and late March (WN993), with additional contributions at various stations, by *C. longipes*, the silicoflagellate *Distephanus speculum* and the athecate dinoflagellate *Gyrodinium spirale.*

By April to early May (WF994 and WN995), *Ceratium longipes* had joined *C. fusus*, *C. tripos*, and *D. norvegica* as dominants, with subdominant contributions at some stations *from D. speculum*, *G. spirale, Protoperidinium depressum* and *P. pallidum*. From mid-May through July (WN996, WF997, WN998, WN999), dominance by *Ceratium longipes* and other congeners, particularly *C. tripos* and *C. furca*, continued, but the thecate dinoflagellates *Dinophysis norvegica* and an unidentified thecate dinoflagellate were subdominant.

In comparison with other years, the screened phytoplankton in the nearfield was typical for this time of year, with the bloom of *Ceratium tripos/longipes* as the major feature of the screened-water dinoflagellate assemblage.

5.3.1.3 Regional Phytoplankton Assemblages

Whole-Water Phytoplankton - During February (WF991, WF992), most farfield station assemblages were dominated at both depths by the same assemblages that dominated nearfield stations. These included unidentified microflagellates, diatoms of the genus *Chaetoceros* (*C. socialis, C. debilis, Chaetoceros* spp.), and *Pseudo-nitzschia pungens* (possibly also including *P. multiseries*). The latter diatom taxon was present throughout the farfield during WF991, but comprised only 5-6% of cells recorded, mainly in Cape Cod Bay, during WF992.

During WF994 (April-May) most farfield stations were dominated by unidentified microflagellates and the same assemblage of *Chaetoceros* spp. recorded for February. *Pseudo-nitzschia pungens* were no longer present in abundances comprising >5% of the total assemblage during this survey.

By WF997 assemblages at both depths at most farfield stations were dominated by microflagellates. However, in Boston Harbor and coastal waters there were subdominant contributions by cryptomonads and the diatoms *Thalassiosira rotula*, a small (< 10 µm) centric diatom, probably of the genus *Thalassiosira*, and *Skeletonema costatum*.

Whole-water phytoplankton assemblages at farfield stations were similar to those in the nearfield, in terms of composition, and absence of a clear spring phytoplankton bloom.

Screened Phytoplankton - In WF991 and WF992, 20 µm-screened surface phytoplankton samples from the farfield were dominated by the assemblages as those recorded for the nearfield. These included several species of the dinoflagellate genus *Ceratium* (*C. fusus, C. tripos*), *Dinophysis norvegica, Prorocentrum micans*, and several species of the genus *Protoperidinium*. During WF992, there were isolated patterns of dominance by other species at single stations, such as *Distephanus speculum* at station F13, and *Gyrodinium spirale* at station F30.

In WF994, surface and subsurface samples were overwhelmingly dominated by *Ceratium tripos,* and *C. fusus,* with increasing contributions by *C. longipes*. *Dinophysis norvegica, Gyrodinium spirale* and *Distephanus speculum* were subdominants at many stations.

Screened samples in WF997 were dominated by several species of the dinoflagellate genus *Ceratium* (*fusus, lineatum, longipes, tripos*) and *Dinophysis norvegica,* with subdominant contributions by other dinoflagellates such as *Protoperidinium pentagonium*, and *Prorocentrum minimum*.

Screened-water dinoflagellate assemblages at farfield stations were similar to those in the nearfield, particularly in terms of the sustained bloom of *Ceratium tripos/fusus/longipes*.

5.3.1.4 Nuisance Algae

There were no blooms of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during February – July, 1999. Some species that have caused harmful blooms in previous years, such as *Phaeocystis pouchetii*, were unrecorded during this period. The toxic dinoflagellate *Alexandrium tamarense* was unrecorded, and potentially-toxic members of the genus *Pseudo-nitzschia* were only sporadically present in low numbers. There was an occurrence of "*Alexandrium* spp." that was not positively identified as *A. tamarense*, based upon a single cell in a single sample (WF994, station F01), at an abundance of 1.4 cells l^{-1}.

Pseudo-nitzschia pungens were found in 20 samples in WF991, and in 4 samples in WF992, but abundance values were < 187 x 10^3 cells l^{-1} (mean = 96 x 10^3 cells l^{-1}) during WF991 and < 94 x 10^3 cells l^{-1} (mean = 66 x 10^3 cells l^{-1}) during WF992. Other single cells of *Pseudo-nitzschia* sp., not identifiable as "*pungens*" because it was impossible to discern the extent of overlap of cells in chains (a diagnostic characteristic), were present at levels of < 72 x 10^3 cells l^{-1} (mean = 47 x 10^3 cells l^{-1}) during WF991.

Although the non-toxic species *P. delicatissima* can be identified with confidence, species reported as *P. pungens* could be either non-toxic *P. pungens*, or domoic-acid-producing *P. multiseries*, but it is impossible to distinguish the two without performing scanning electron microscopy counts on intercostal poroids on the underside of acid-washed thecae. *Pseudo-nitzschia pungens* and *Pseudo-nitzschia* spp. counts did not exceed the 5 x 10^5 cells l^{-1} threshold for domoic acid toxicity used in Canadian waters in the 31 samples where either *P. pungens* or *Pseudo-nitzschia* spp. were present in WF991 or WF992.

5.3.2 Zooplankton

5.3.2.1 Seasonal Trends in Total Zooplankton Abundance

Total zooplankton abundance at nearfield stations generally increased from February through June (WF991-WF997) with slight declines during WN998 and WN999 in July (Table 5-3, Figures 5-17 to 5-20). The values at nearfield of 100-200 x 10^3 animals m^{-3} recorded for WF997 (Fig. 5-20), were among the highest during the entire 1992-1999 baseline (Turner et al., 1999).

Total zooplankton abundance at farfield stations in February was low (over half of the stations < 20 x 10^3 animals m^{-3} in WF991 and 2/3 of the stations < 40 x 10^3 animals m^{-3} in WF992) (Figures 5-17 and 5-18). By April (WF994), total zooplankton abundance at farfield stations had generally increased, with values at two of the stations of 100-200 x 10^3 animals m^{-3} (Fig. 5-19). The spring-summer increase in farfield zooplankton abundance continued through June (WF997), with 9 of 13 values >100 x 10^3 animals m^{-3} and 5 of 13 values >200 x 10^3 animals m^{-3} (Figure 5-20). The astonishing maximum value exceeding 500 x 10^3 animals m^{-3} at station F30 in Boston Harbor (Figure 5-20) is the highest zooplankton abundance recorded for the entire 1992-1999 baseline (Turner et al., 1999).

Table 5-3. Nearfield and Farfield Average and Ranges of Abundance (10^3 Animals m^{-3}) for Zooplankton

Survey	Dates (1999)	Nearfield Mean	Nearfield Range	Farfield Mean	Farfield Range
WF991	2/2 – 2/8	29.2	19.1 - 36.8	16.9	4.7 - 32.3
WF992	2/23 – 2/28	41.6	0.2 - 72.3	28.4	12.4 - 67.7
WN993	3/20	31.5	30.4 - 32.5	NA	NA
WF994	4/1 to 5/6*	44.0	5.8 - 112.8	38.1	4.1 - 196.0
WN995	5/5	73.9	73.7 - 74.1	NA	NA
WN996	5/12	120.0	116.6 - 123.4	NA	NA
WF997	6/14 – 6/19	157.6	120.5 - 201.2	183.6	75.1 - 518.5
WN998	7/7	105.4	46.0 - 164.8	NA	NA
WN999	7/20	95.7	78.8 - 112.6	NA	NA

NA- Data not available because the farfield stations were not sampled during this survey.

*Due to severe weather, the WF994 survey was completed over the course of six days in April and May – nearfield plankton samples were collected April 11th and farfield plankton samples were collected April 1, 6, 11, 26, and May 6.

5.3.2.2 Nearfield Zooplankton Community Structure

During early February (WF991) the nearfield zooplankton assemblages (Figure 5-17) were dominated by gastropod veligers (39-61%, mean = 50%), copepod nauplii (21-35%, mean = 27%), and copepodites of *Oithona similis* (7-12%, mean = 10%).

In late February (WF992), the nearfield zooplankton (Figure 5-18) continued to be dominated by gastropod veligers (53-90%, mean = 75%), with lesser contributions by copepod nauplii and *Oithona similis* copepodites. A similar assortment was found in March (WN993) nearfield dominance by gastropod veligers (37-42%, mean = 40%) was shared with copepod nauplii (29-36%, mean = 33%), with lesser contributions by *Oithona similis* copepodites (9-10%) and *Oikopleura dioica* (6-11%).

At nearfield stations during April-May (WN994) zooplankton assemblages (Figure 5-19) were dominated by copepod nauplii (26-49%, mean = 34%) and copepodites of *Oithona similis* (26-31%, mean = 29%)

with lesser contributions at some stations by *Pseudocalanus* sp. copepodites, *Oikopleura dioica*, gastropod veligers and barnacle nauplii.

By May, during WN995 and WN996, nearfield zooplankton assemblages were dominated by copepod nauplii, comprising 42% and 31-61% during WN995 and WN996, respectively, with subdominance during these surveys of copepodites of *Oithona similis* (26-34% and 115-19%, respectively) and *Pseudocalanus* spp. (10-17% and 5-22%, respectively).

At nearfield stations during June (WF997), zooplankton assemblages (Figure 5-20) were dominated by bivalve veligers (32-46%, mean = 40%), copepodites of *Pseudocalanus* spp. (19-30%, mean = 24%), *Oithona similis* (11-12%), and copepod nauplii (7-13%, mean = 11%). Dominance by copepodites of *Oithona similis* and *Pseudocalanus* spp. and copepod nauplii continued through July (WN998 and WN999), with the contribution of bivalve veligers declining compared to June.

5.3.2.3 Regional Zooplankton Assemblages

Zooplankton assemblages at farfield stations during early February (WF991) were somewhat different from those in the nearfield (Figure 5-17). Rather than gastropod veligers as dominants, there was dominance by copepod nauplii (23-56%, mean = 41%) and *Oithona similis* copepodites (0-23%, mean = 12%). Barnacle nauplii comprised 6-43% (mean = 27%) of the animals counted at the six coastal and Harbor stations where they occurred (Figure 5-17).

In late February (WF992), however, dominance by copepod nauplii and *Oithona similis* copepodites had been supplanted by gastropod veligers, which comprised 14-80% (mean = 46%) of animals counted at the 10 of 12 farfield stations where they occurred (Figure 5-18). Copepod nauplii occurred at all 12 farfield stations, accounting for 11- 45% (mean = 27%) of animals present, whereas *Oithona similis* copepodites accounted for > 5% of the catch at only 8 of 12 farfield stations, comprising 7-12% (mean = 14%) at these stations.

In April-May during WF994 (Figure 5-19), copepod nauplii were dominant at all farfield stations (15-40%, mean = 27%), as were *Oithona similis* copepodites (6-41%, mean = 19%) at all stations except station F30, the most-inshore station in Boston Harbor. Gastropod veligers comprised 6-25% (mean = 16%) at only 7 farfield stations, clearly in decline from the levels of WF992. *Oikopleura dioica* comprised 8-20% (mean = 16%) at the 6 farfield stations where they comprised >5% of total animals counted.

During June (WF997) farfield zooplankton assemblages (Figure 5-20) were dominated by bivalve veligers at 9 of 10 stations (6-81%, mean = 36%). Copepod nauplii, were recorded at levels > 5% of total at only 6 stations (8-40%, mean = 17%), and copepodites of *Oithona similis* accounted for 6-14% (mean = 9%) of animals counted at 6 of 10 stations, and *Pseudocalanus* spp. comprised 9-24% (mean = 17%) at 7 of 10 stations. Copepodites of *Temora longicorni*s were sporadically recorded as 6 -15% of animals counted at various coastal, offshore, and boundary stations, but comprised 27% of total animals at station F31 in Boston Harbor. Large contributions by meroplankters were site-specific. Polychaete larvae were recorded in abundance for only stations F23 and F30 in Boston Harbor, but at those sites they accounted for 18 and 78% of animals, respectively. Similarly, gastropod veligers were recorded in abundance only at the two Cape Cod Bay stations (F01 & F02), but they comprised 15 and 66% of total animals, respectively, at those two stations.

An extremely interesting aspect of the farfield zooplankton distributions is the abnormally low abundance of *Acartia* spp. during the early part of 1999. Since *Acartia* spp. inhabit primarily low-salinity Harbor waters, their low abundance may reflect the prolonged drought in the mid-Atlantic and New England area from winter through mid summer of 1999. During WF991, *Acartia* spp. accounted for > 5% of the total zooplankton only at station F30, the innermost station in Boston Harbor. There, combined abundances of copepodites, females and males of *Acartia hudsonica* totaled only 754 m^{-3}. Copepodites and males of this species were sporadically recorded at 8 of 15 other stations, but at levels < 100 m^{-3}, and < 5% of total animals. During WF992, *Acartia* spp. never accounted for > 5% of totals, with maximal levels of 338 m^{-3} at station F23 in Boston Harbor. At 8 of 15 other stations, abundances were < 215 m^{-3}. During WF994, *Acartia* spp. were > 5% of total animals only at station F30 in Boston Harbor (6%, 844 copepods m^{-3}). They were sporadically recorded at 9 of 15 other stations, but never at abundances > 563 m^{-3}. These abundances are extremely low compared to those recorded at the same times of the year during previous years (Figure 5-21). By June (WF997) *Acartia* spp. abundance comprised > 5% of total zooplankton only at station F24 (6%, 5,678 copepodites m^{-3}), but *Acartia* spp. adults and copepodites were recorded at 7 additional Harbor, coastal and nearfield stations at combined abundances ranging from 237 to 7,777 copepods m^{-3}.

In summary, zooplankton assemblages during the first half of 1999 were comprised of taxa recorded for the same time of year in previous years, but levels of *Acartia* spp. were unusually low, possibly due to drought, and contributions of meroplankton such as bivalve and gastropod veligers and polychaete larvae were unusually high.

5.4 Summary of Water Column Biological Events

- Areal production at the nearfield stations was relatively high during the winter/spring of 1999 reaching values of >1500 mg C m^{-2} d^{-1} at both stations in late February and early April. Nearfield areal production declined in May and remained relatively low during the last four surveys.
- In contrast to 1998, areal production in 1999 followed patterns typically observed in prior years. Distinct winter-spring phytoplankton blooms were observed at both nearfield stations during the sampling period. The bloom in 1999 reached peak values of >2000 mg C m^{-2} d^{-1} and lasted from February through April and represents a return to expected patterns following the somewhat unusual cycle observed last year.
- The Harbor station F23 generally exhibits a gradual pattern of increasing areal production from winter through summer rather than the distinct winter-spring peaks observed at the nearfield sites. This was the case in 1999 for station F23 . Production values increased gradually from February through June Boston Harbor reaching values of >2500 mg C m^{-2} d^{-1} in April and June.
- In the nearfield, chlorophyll-specific areal production was relatively low at the start of the sampling period then gradually increased at both stations until the seasonal maxima were reached during the mid-May survey (>1100 mg C mg chl a^{-1} d^{-1}). Chlorophyll-specific production was relatively constant and low at the Boston Harbor station over this time period (<300 mg C mg chl a^{-1} d^{-1}).
- The distribution of chlorophyll-specific production indicates that the efficiency of production was high relative to the amount of biomass present at the nearfield stations, but low at the Harbor site.
- Respiration rates were generally low throughout the region (<0.10 μMO_2 hr^{-1}) in February and March, increased 2 to 4-fold in the nearfield by April (0.1 to 0.4 μMO_2 hr^{-1}) and reached a maximum for the time period in the nearfield in early May (0.5 to 0.8 μMO_2 hr^{-1} at station N18).
- The increase in respiration rates in April was coincident with the peak production values observed for the winter-spring bloom and the cessation of the bloom by early May fueled the high respiration rates as the readily available labile organic material was degraded.
- POC concentrations increased during the winter-spring bloom from February to April and then decreased from April to July consistent with the pattern observed in chlorophyll over this time period.
- By early May, significant decreases in POC and chlorophyll concentrations and production rates had occurred due to the senescence of the winter-spring bloom. Carbon-specific respiration rates, however, increased considerably and achieved maxima of 0.035-0.045 μMO_2 μMC^{-1} hr^{-1}, likely in response to elevated DOC concentrations.

- POC concentrations were considerably higher at Boston Harbor station F23 in comparison to the nearfield stations, but the carbon-specific respiration rates remained low ($\leq 0.005\ \mu MO_2\ \mu MC^{-1}\ hr^{-1}$) over this time period suggesting that the POC found in the Harbor was recalcitrant degraded or detrital material.
- Total phytoplankton abundances in nearfield surface whole water samples were variable from February through May, reached maxima of >3 million cells per liter in April and declined in numbers in June and July. A similar pattern was observed at the farfield stations.
- Whole-water phytoplankton assemblages were dominated by unidentified microflagellates and several species of the centric diatom genus *Chaetoceros*. This is typical for the first half of the year in terms of taxonomic composition, however, there was no clear spring phytoplankton bloom.
- Perhaps the singular phytoplankton event of this period was the bloom of *Ceratium furca /C. tripos/* C. *longipes* which continued from the previous year, and exhibited sustained increases from February through July.
- Chlorophyll and production data indicated that a sustained winter-spring bloom occurred from February to April of 1999. This was not clearly represented in the phytoplankton abundance data, but winter-spring increases in *Ceratium* spp. and presence of chain forming *Chaetoceros* spp. in relatively high numbers may have led to this seeming discrepancy.
- There were no blooms of harmful or nuisance phytoplankton species in Massachusetts and Cape Cod Bays during February – July, 1999. *Phaeocystis pouchetii*, and the dinoflagellate *Alexandrium tamarense* were not recorded. *Pseudo-nitzschia pungens* and *Pseudo-nitzschia* spp. counts in some samples exceeded 10^5 cells l^{-1} in WF991 and WF992, but were below the 5×10^5 cells l^{-1} threshold.
- Total zooplankton abundance generally increased from February through June. Nearfield counts of 100-200 x 10^5 animals m^{-3} during WF997 were among the highest for the entire 1992-1999 baseline and the astonishing maximum value of >500 x 10^3 animals m^{-3} at station F30 in Boston Harbor is the highest zooplankton abundance recorded for the entire 1992-1999 baseline.
- Zooplankton assemblages during the first half of 1999 were comprised of taxa recorded for the same time of year in previous years, but levels of *Acartia* spp. were unusually low, possibly due to drought, and contributions of meroplankton such as bivalve and gastropod veligers and polychaete larvae were unusually high.

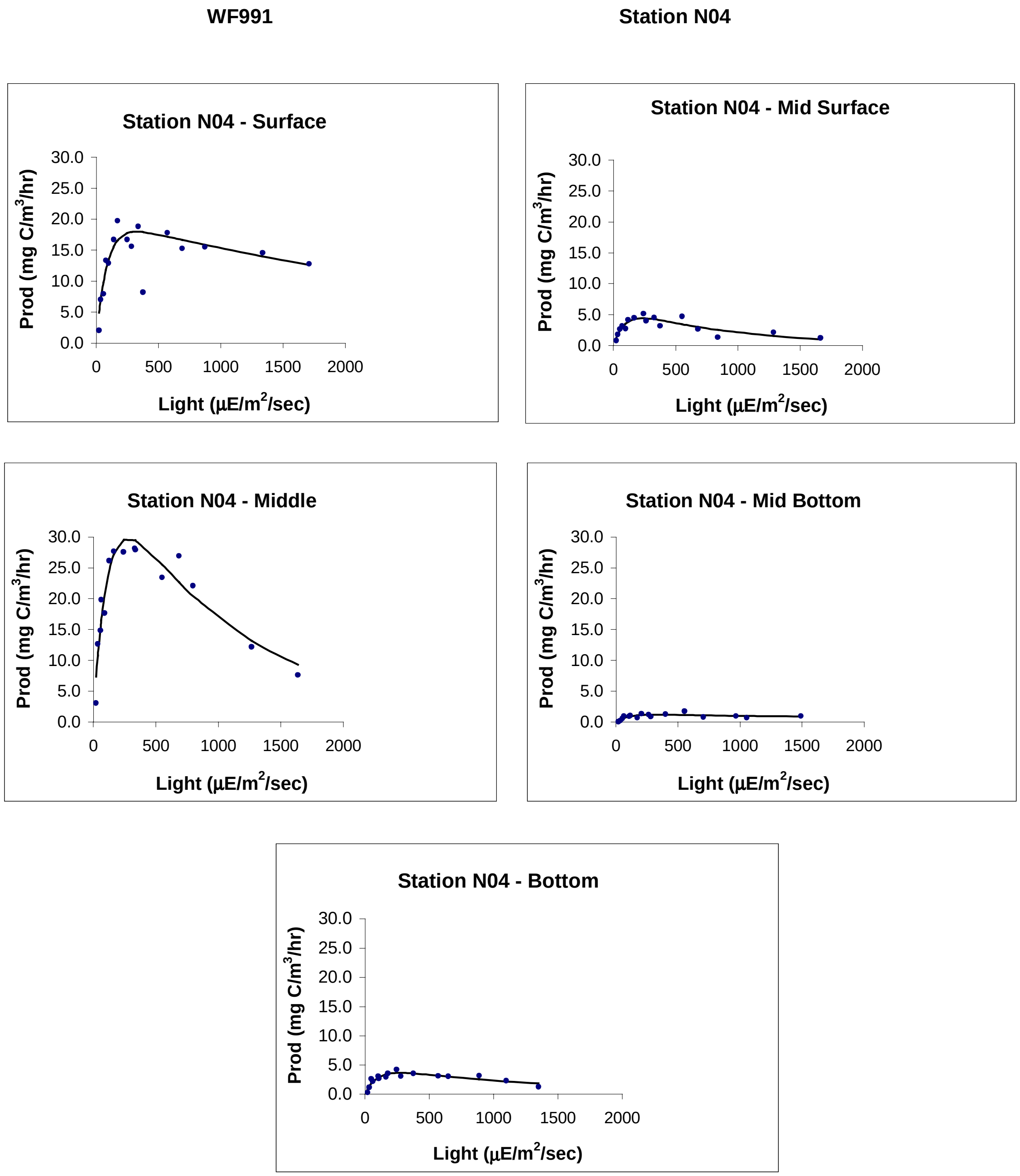


Figure 5-1. An Example Photosynthesis-Irradiance Curve From Station NO4 Collected in February 1999

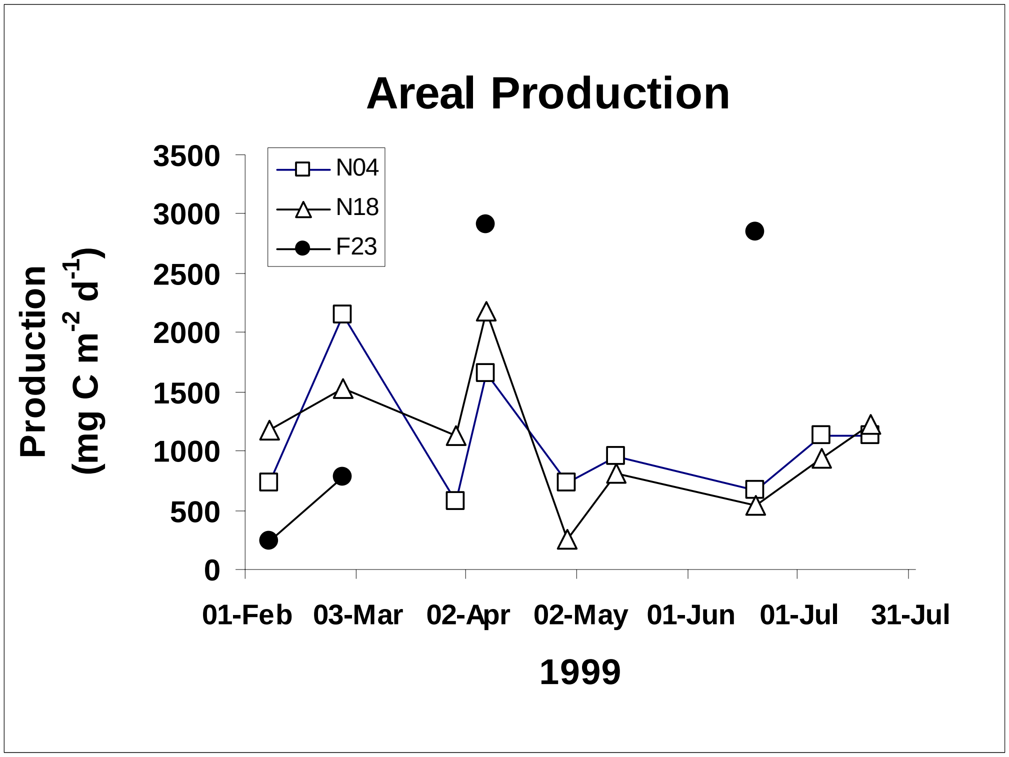


Figure 5-2. Time-Series of Areal Production (mgCm^{-2}d^{-1}) for Productivity Stations

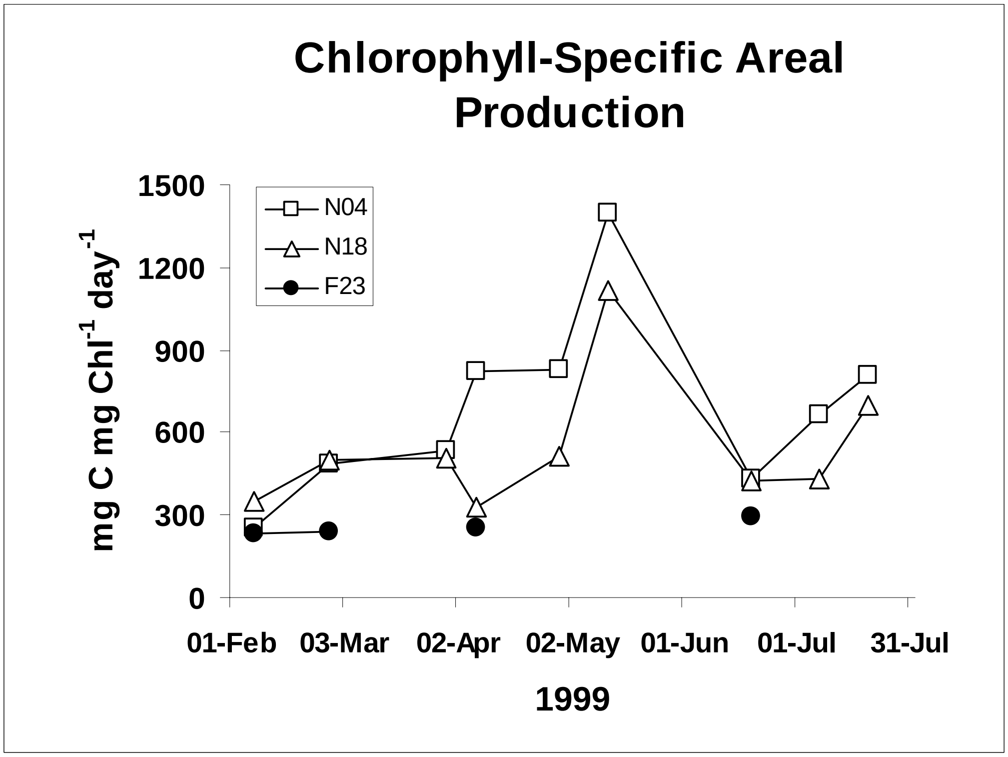


Figure 5-3. Time-Series of Chlorophyll-Specific Areal Production (mgCmgChl^{-1}d^{-1}) for Productivity Stations

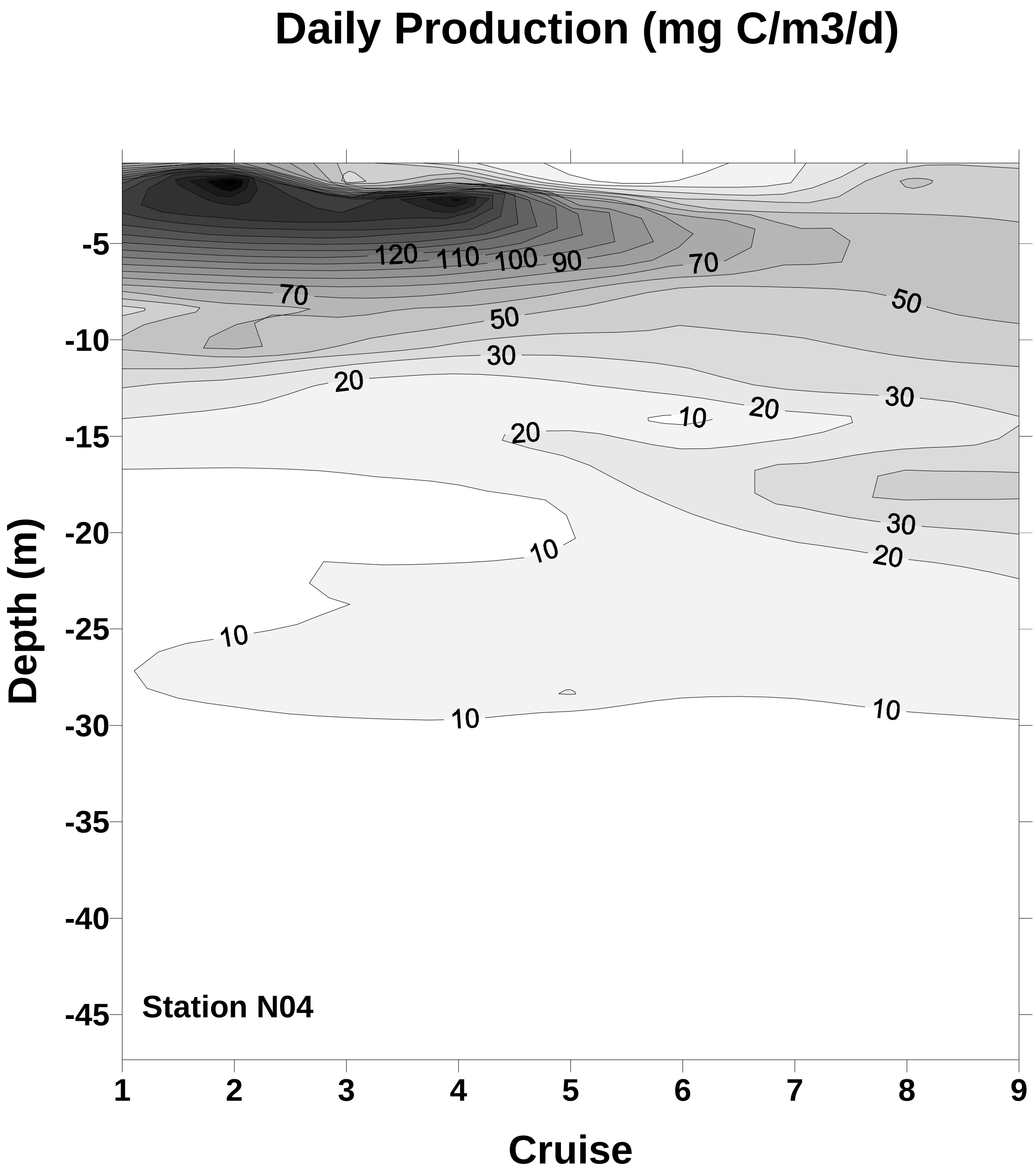


Figure 5-4. Time-Series of Contoured Daily Production (mgCm^{-3}d^{-1}) Over Depth at Station N04

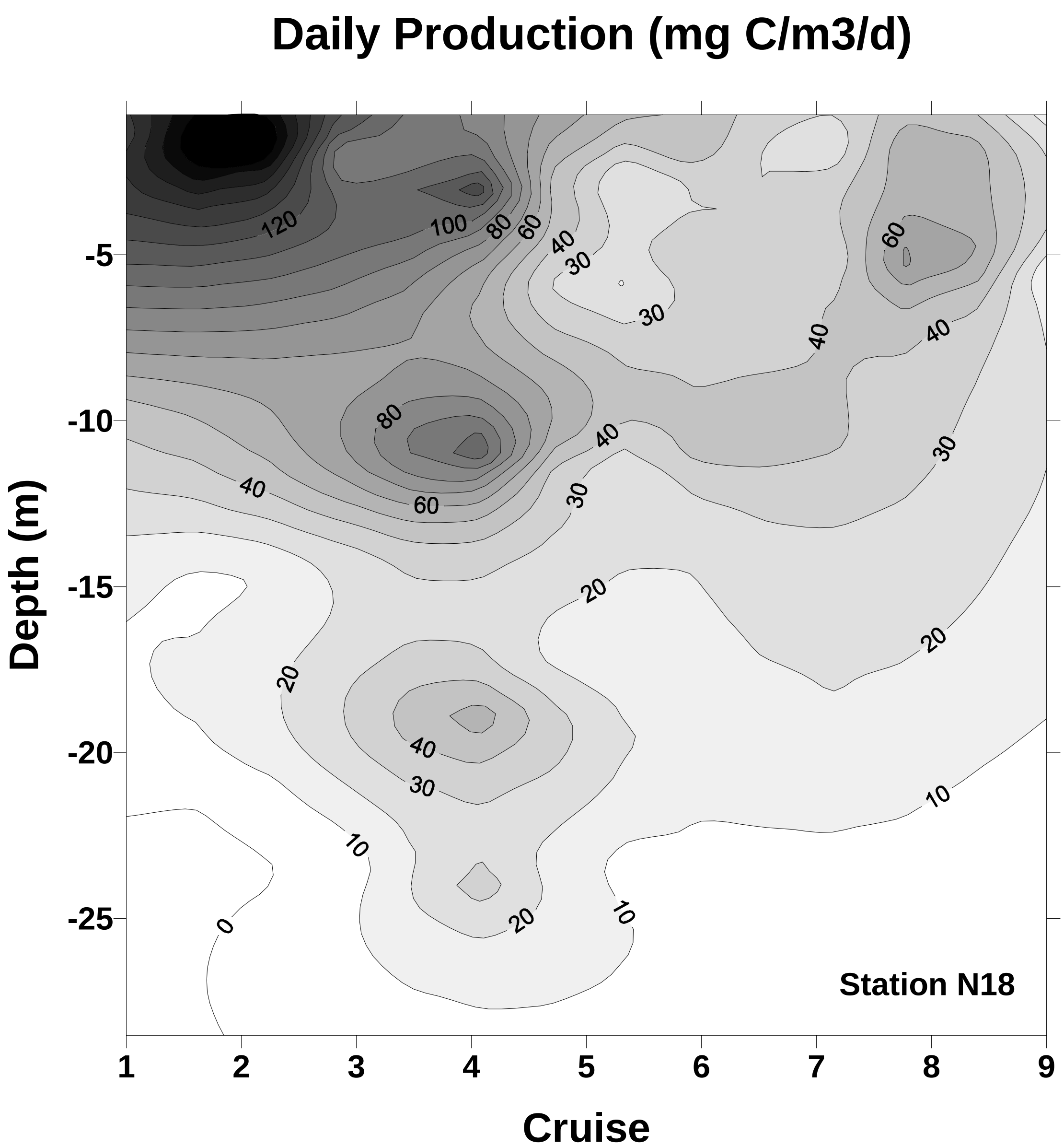


Figure 5-5. Time-Series of Contoured Daily Production ($mgCm^{-3}d^{-1}$) Over Depth at Station N18

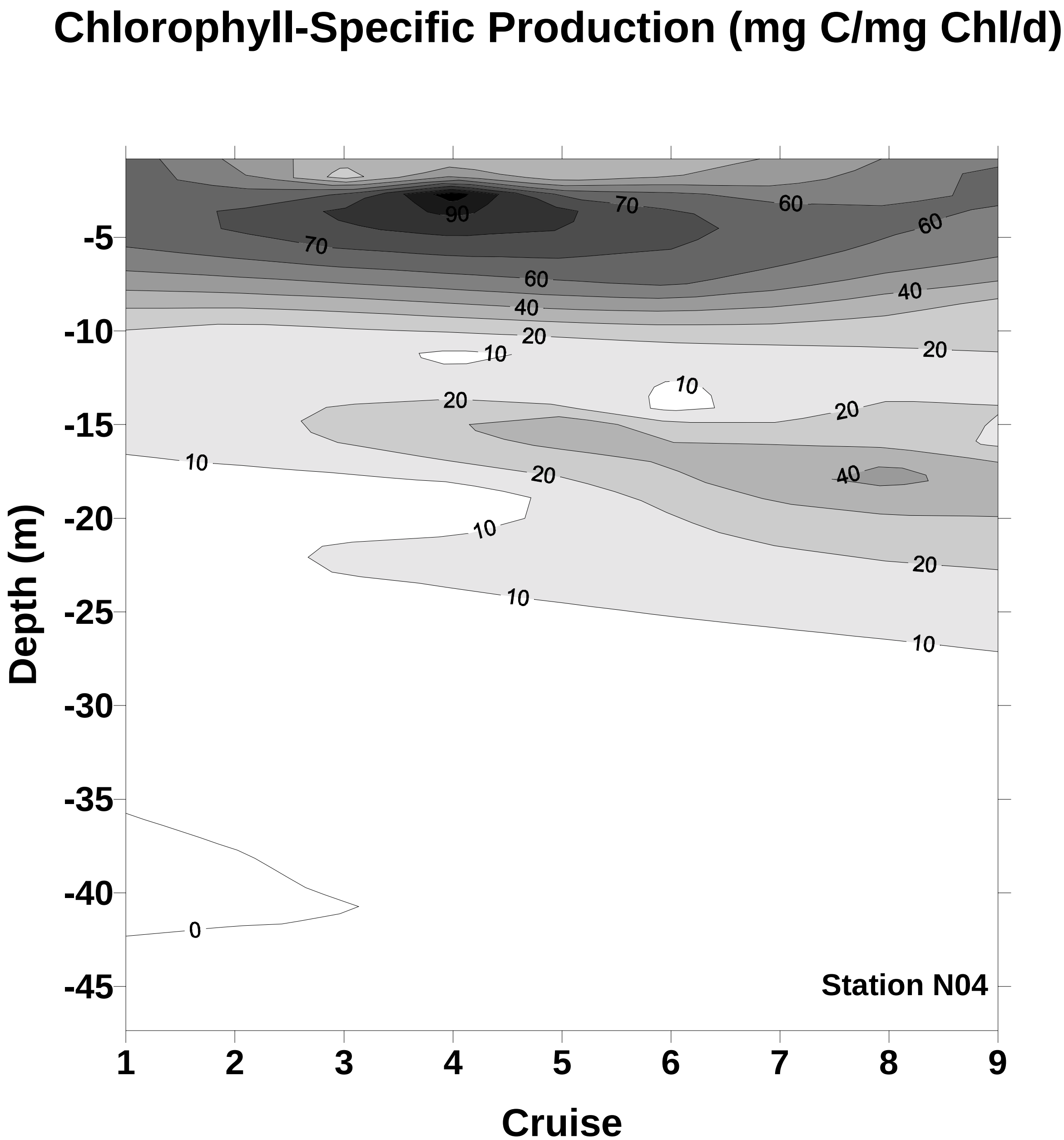


Figure 5-6. Time-Series of Contoured Chlorophyll-Specific Production ($mgCmgChl^{-1}d^{-1}$) at Station N04

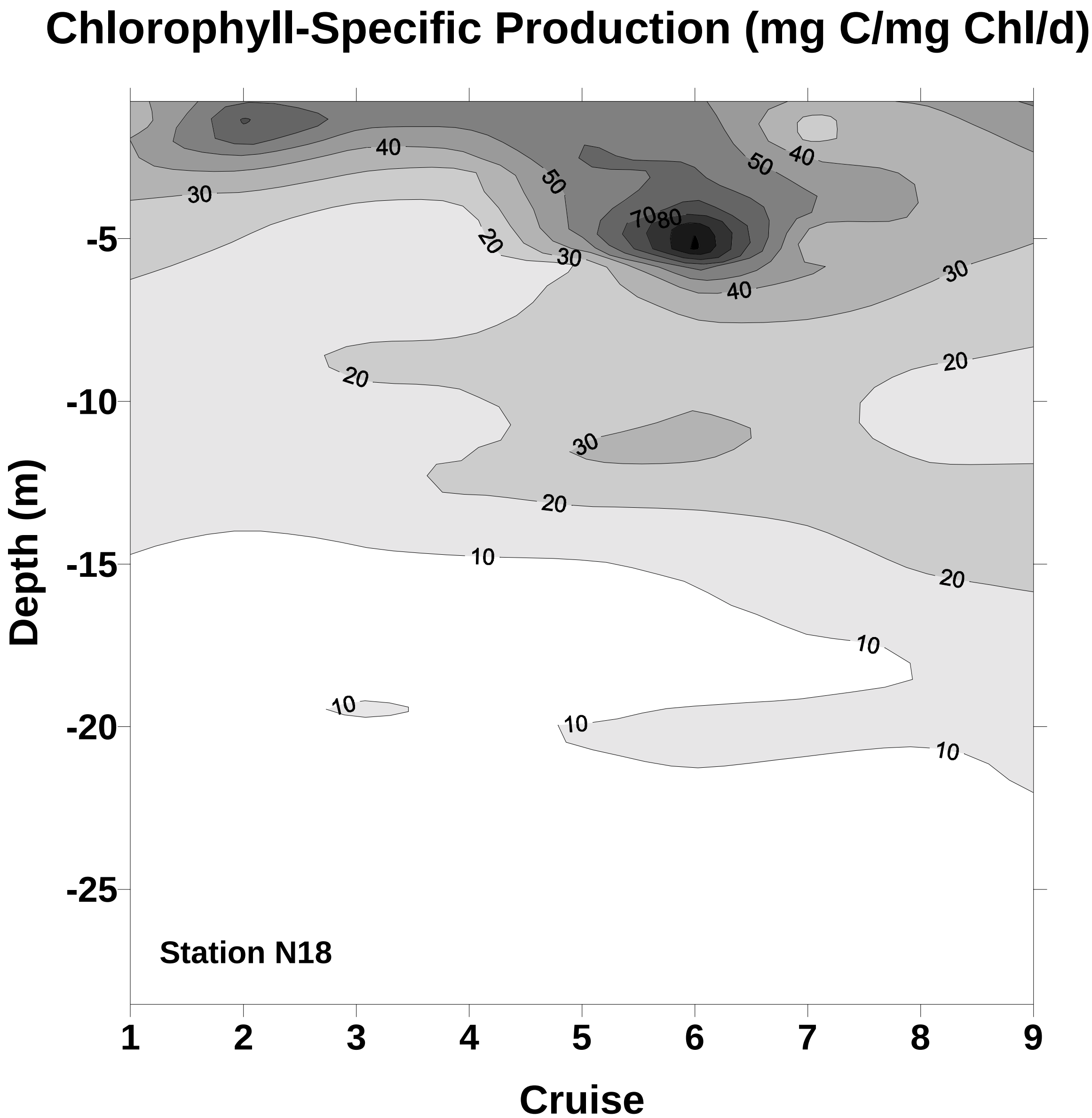


Figure 5-7. Time-Series of Contoured Chlorophyll-Specific Production ($mgCmgChl^{-1}d^{-1}$) at Station N18

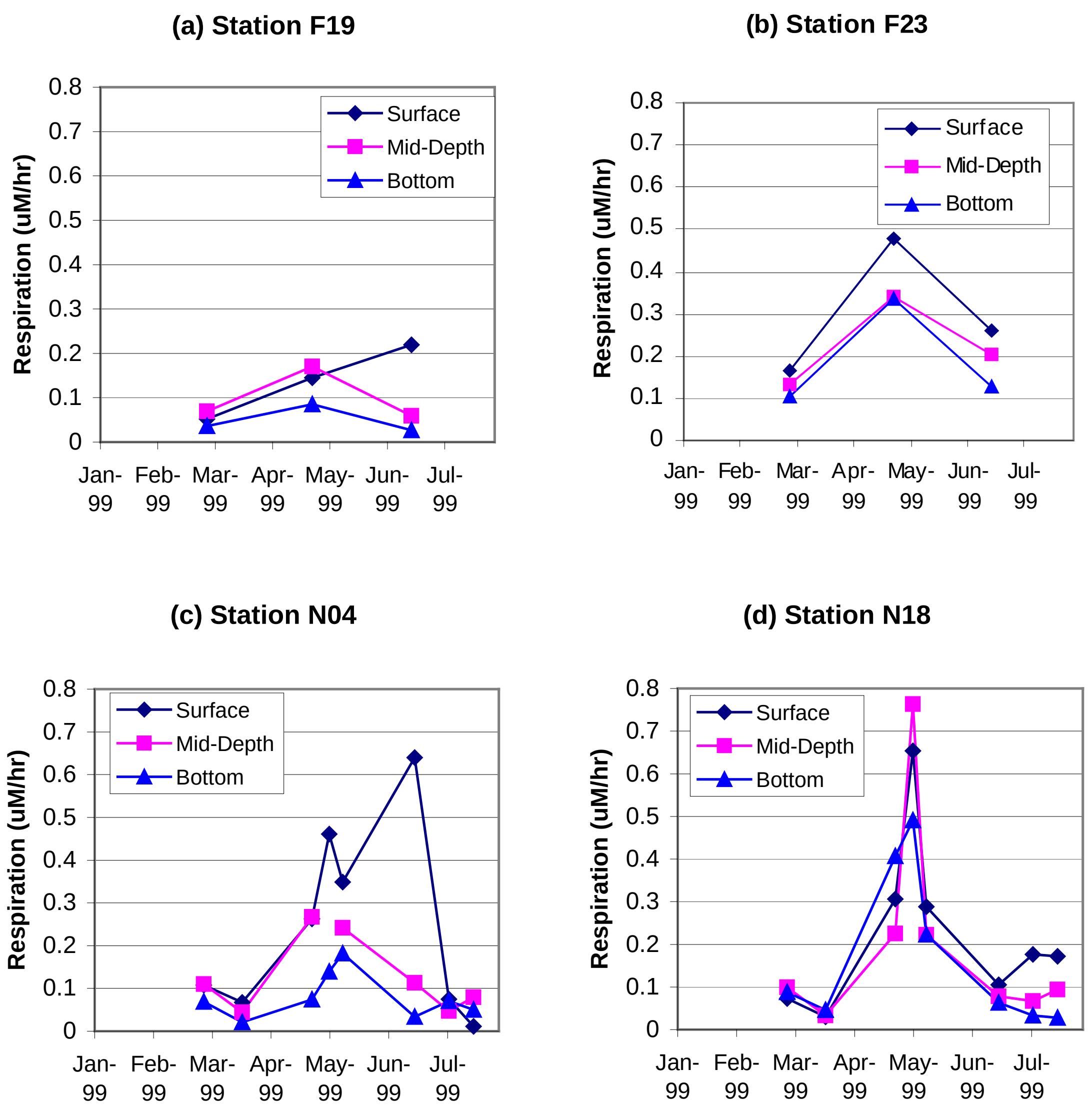


Figure 5-8. Time-Series Plots of Respiration Stations F19, F23, N04, and N18

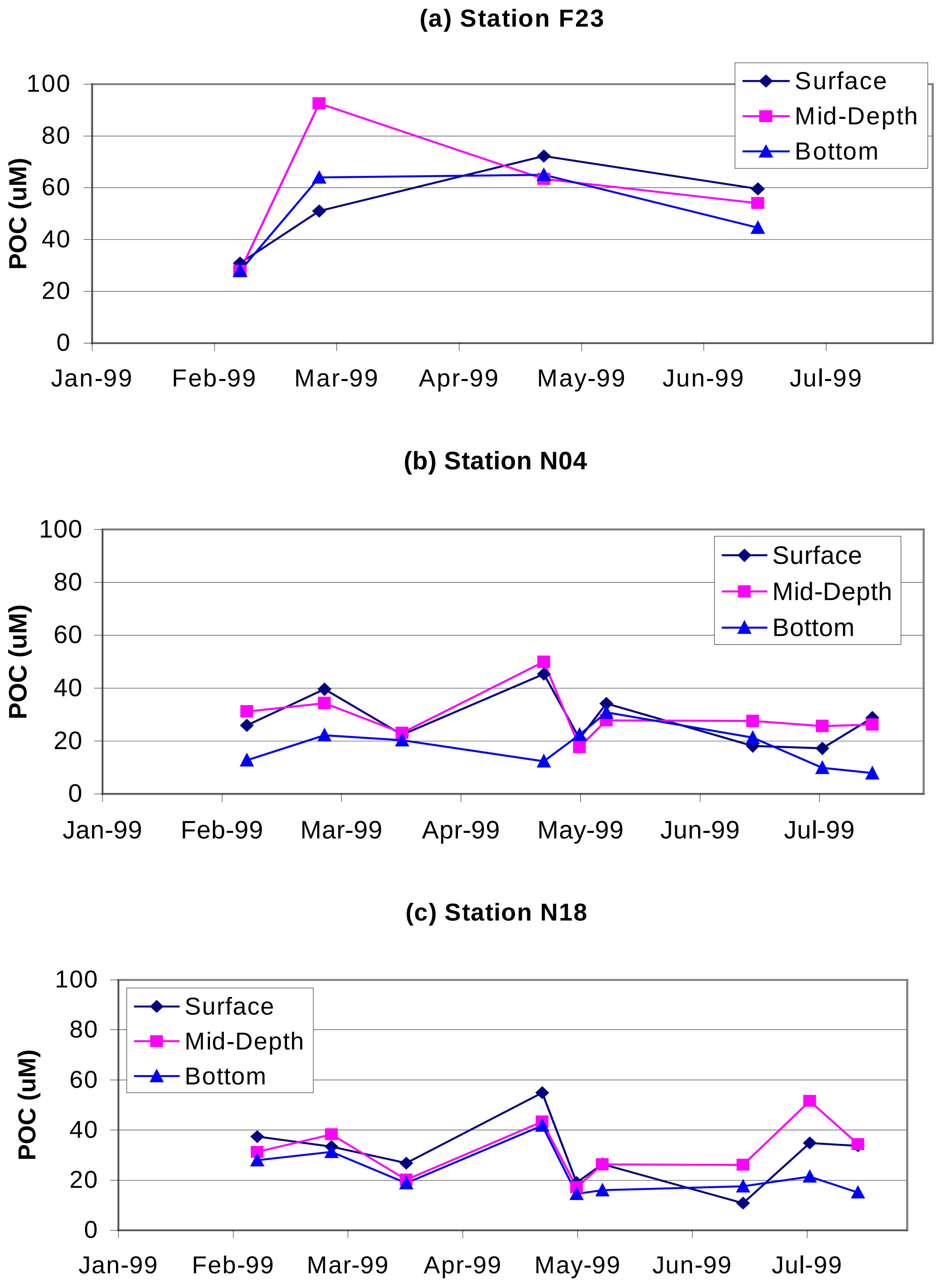


Figure 5-9. Time-Series Plots of POC at Stations F23, N04, and N18

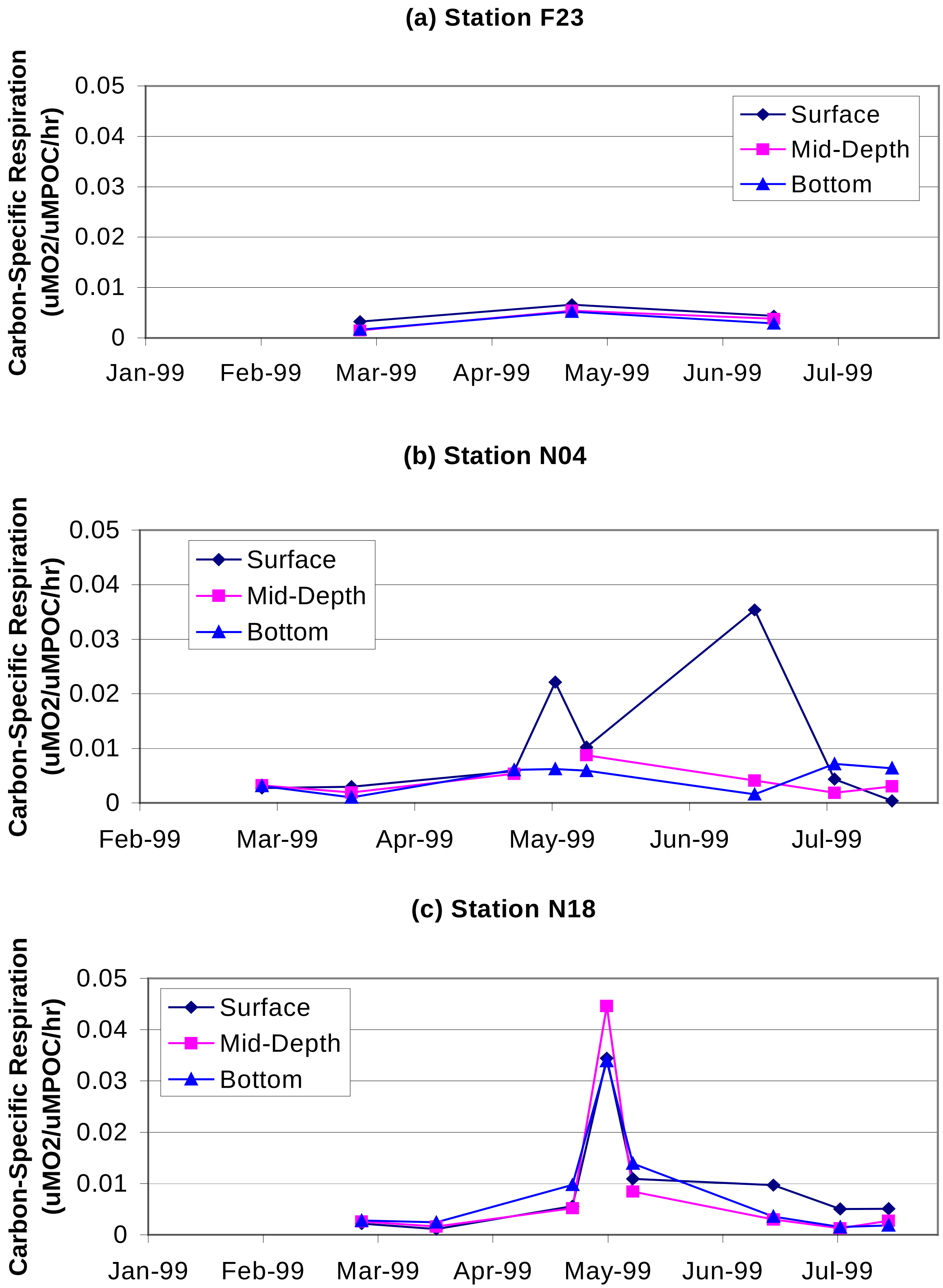


Figure 5-10. Time-Series Plots of Carbon-Specific Respiration at Stations F23, N04, and N18

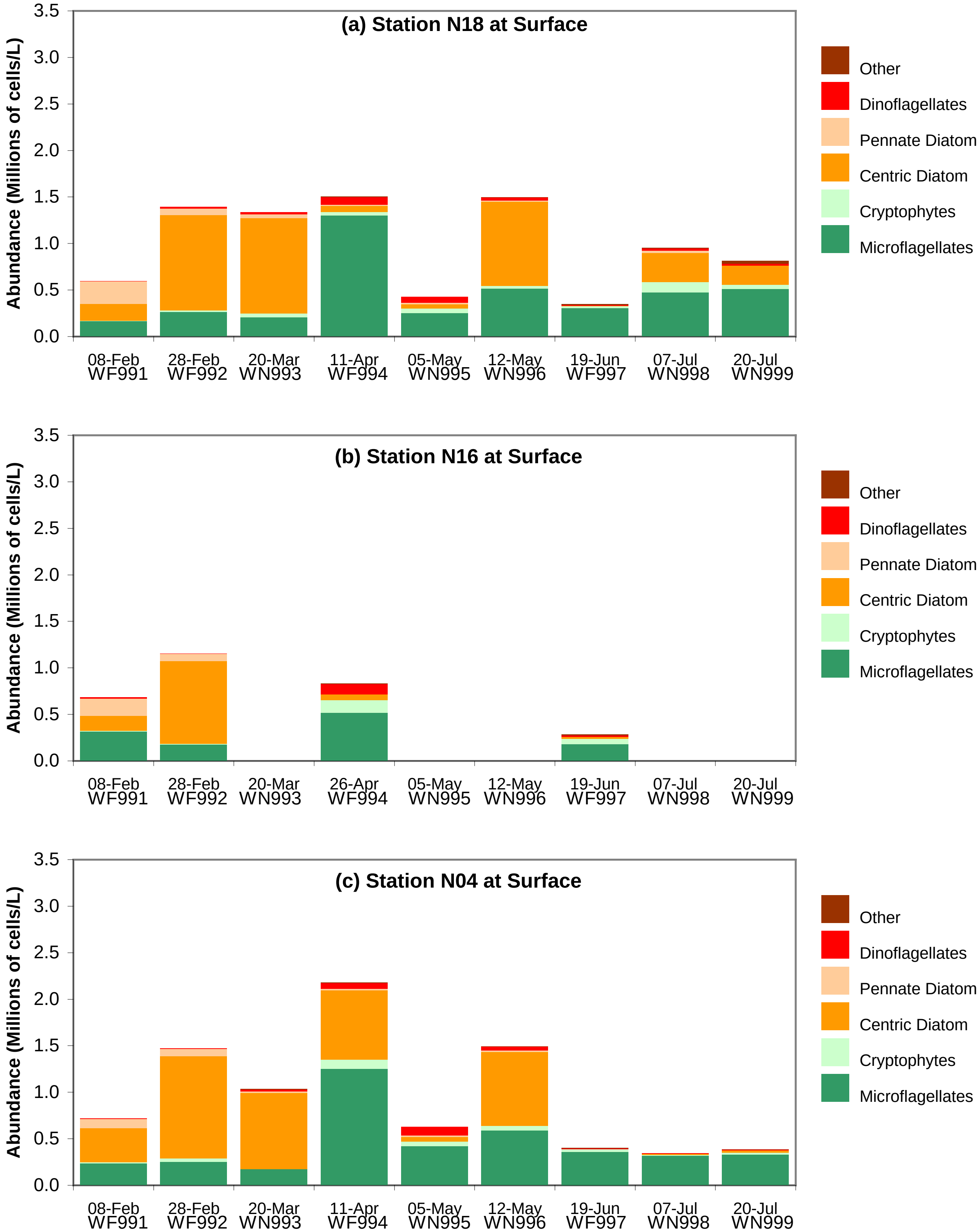


Figure 5-11. Phytoplankton Abundance by Major Taxonomic Group, Nearfield Surface Samples

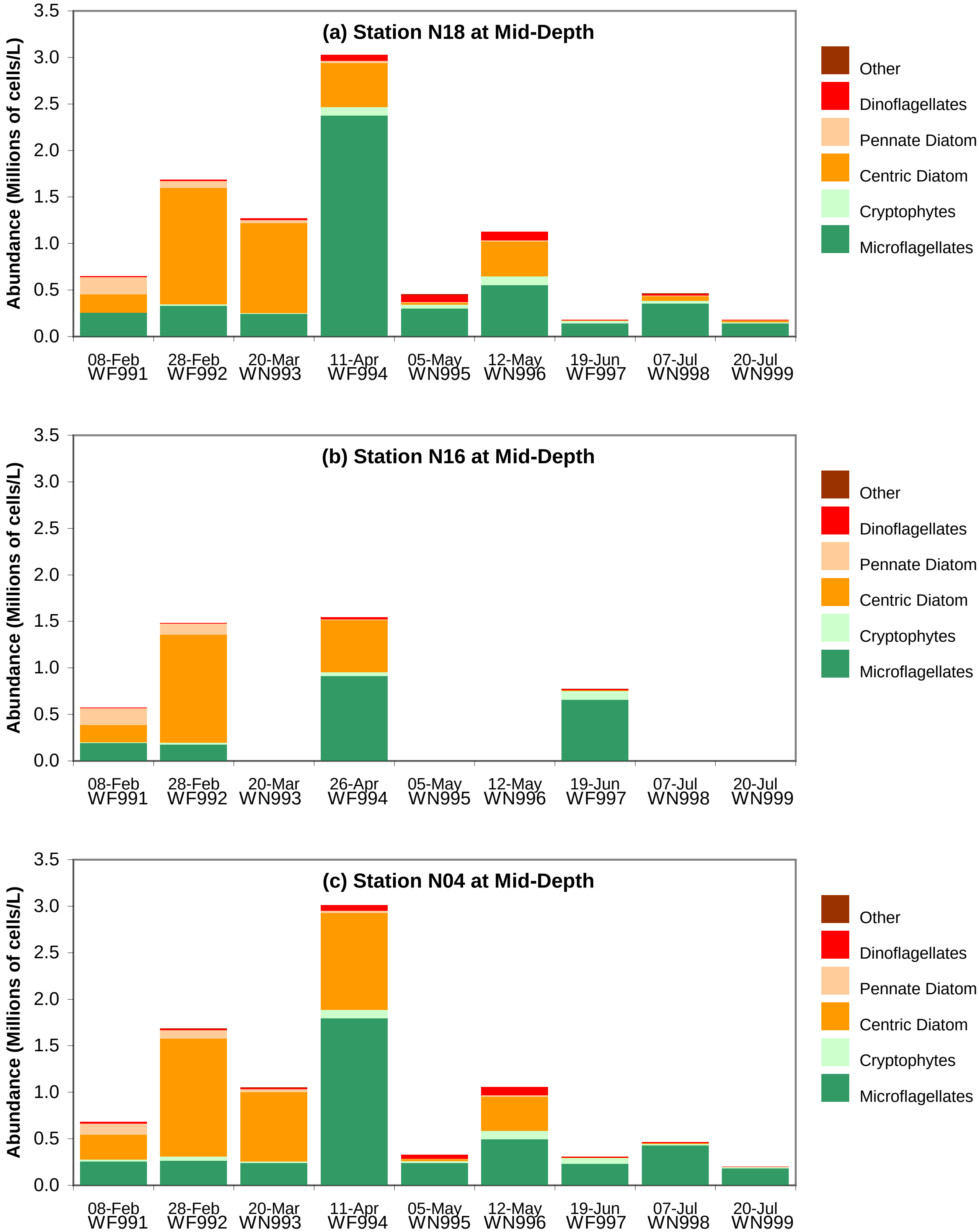


Figure 5-12. Phytoplankton Abundance by Major Taxonomic Group, Nearfield Mid-Depth Samples

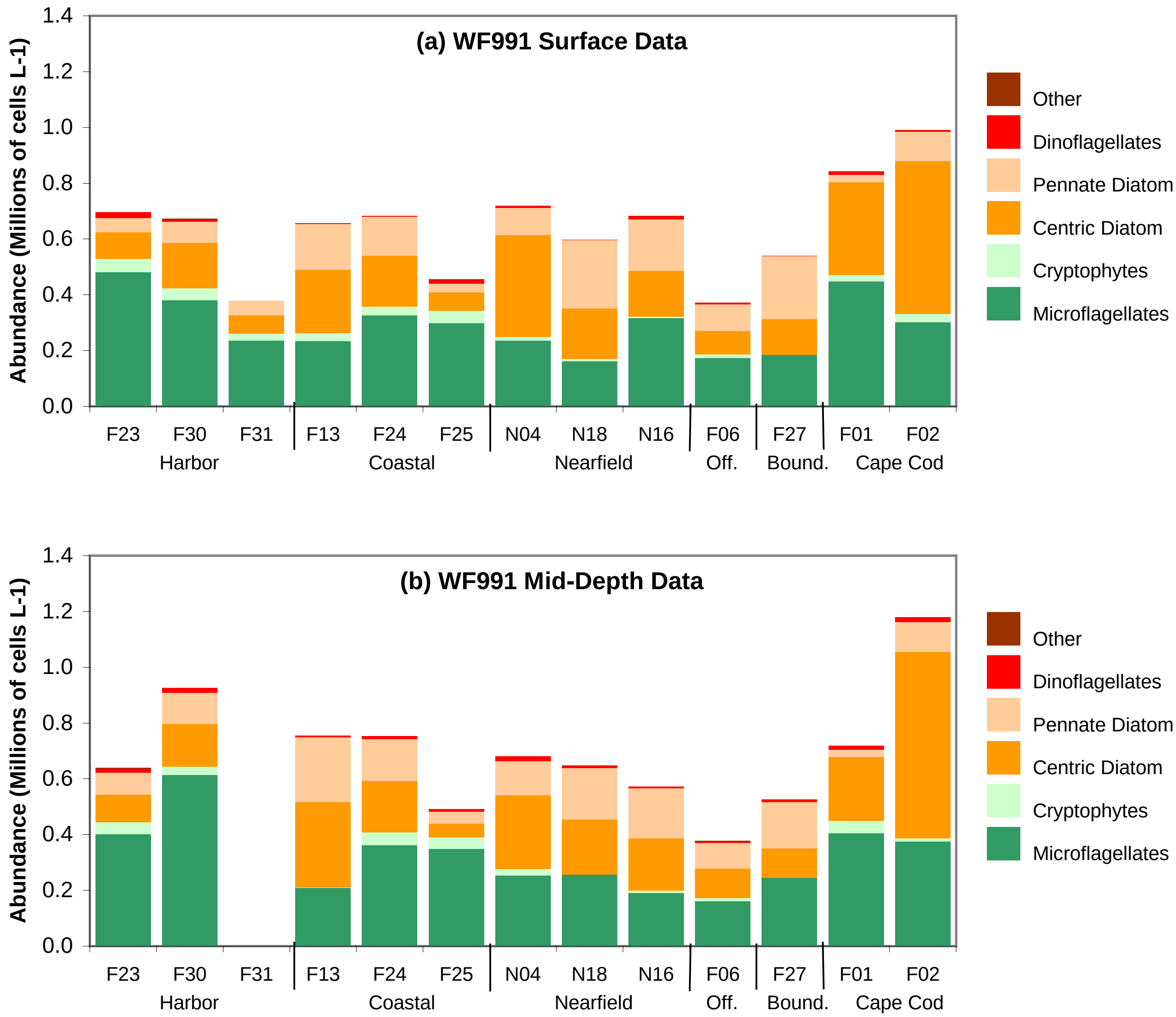


Figure 5-13. Phytoplankton Abundance by Major Taxonomic Group – WF991 Farfield Survey Results February 2 – 8, 1999

Figure 5-14. Phytoplankton Abundance by Major Taxonomic Group – WF992 Farfield Survey Results February 23 – 28, 1999

Figure 5-15. Phytoplankton Abundance by Major Taxonomic Group – WF994 Farfield Survey Results April 1 – May 6, 1999

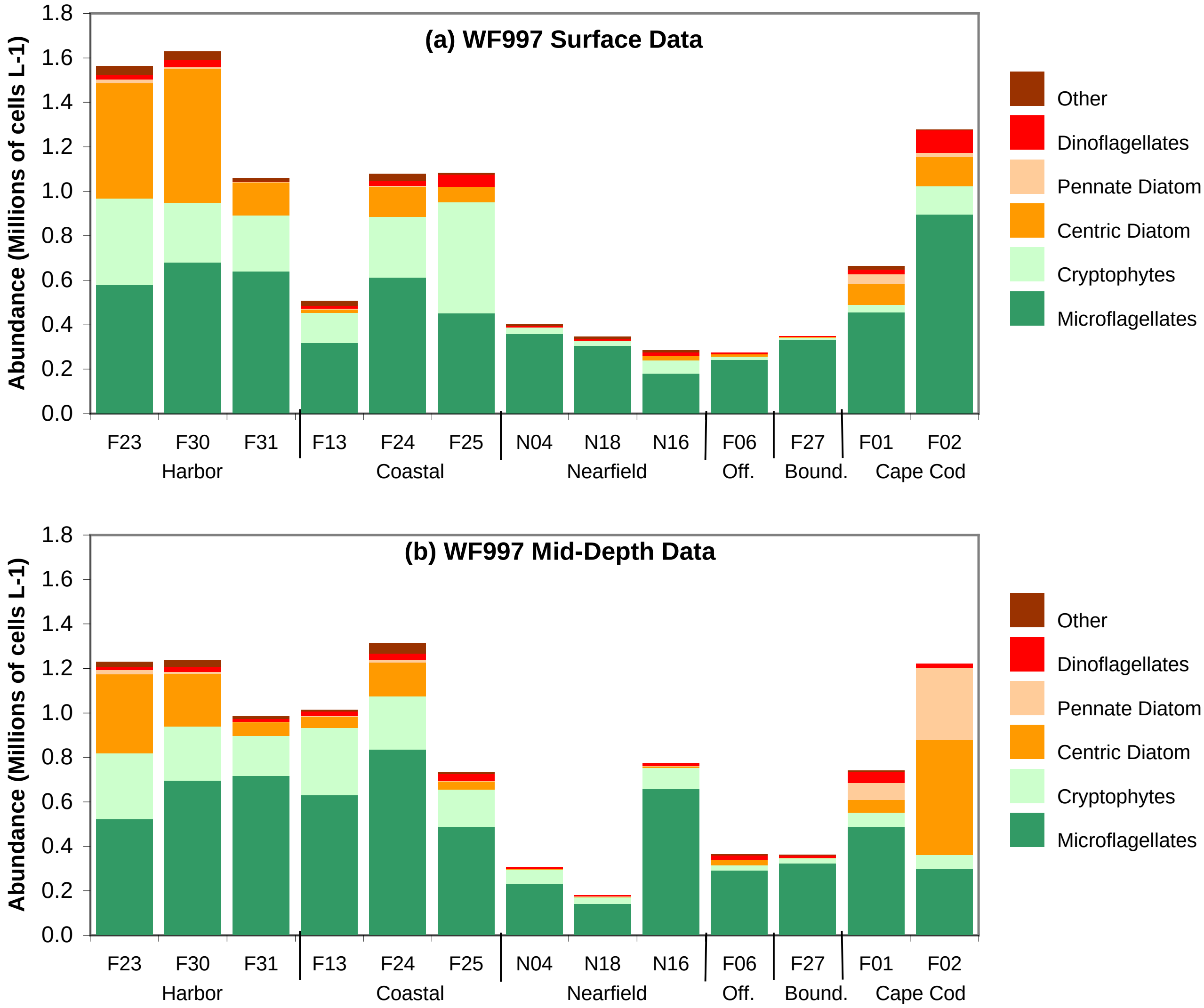


Figure 5-16. Phytoplankton Abundance by Major Taxonomic Group – WF997 Farfield Survey Results June 14 – 19, 1999

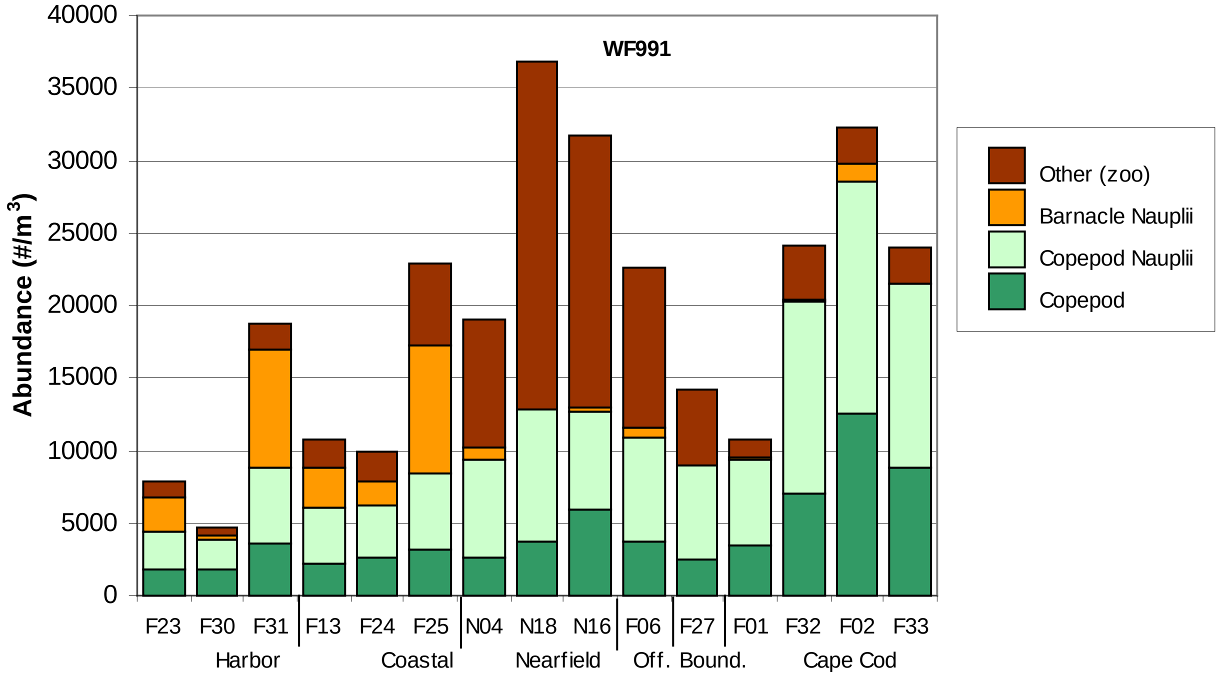


Figure 5-17. Zooplankton Abundance by Major Taxonomic Group – WF991 Farfield Survey Results February 2 – 8, 1999

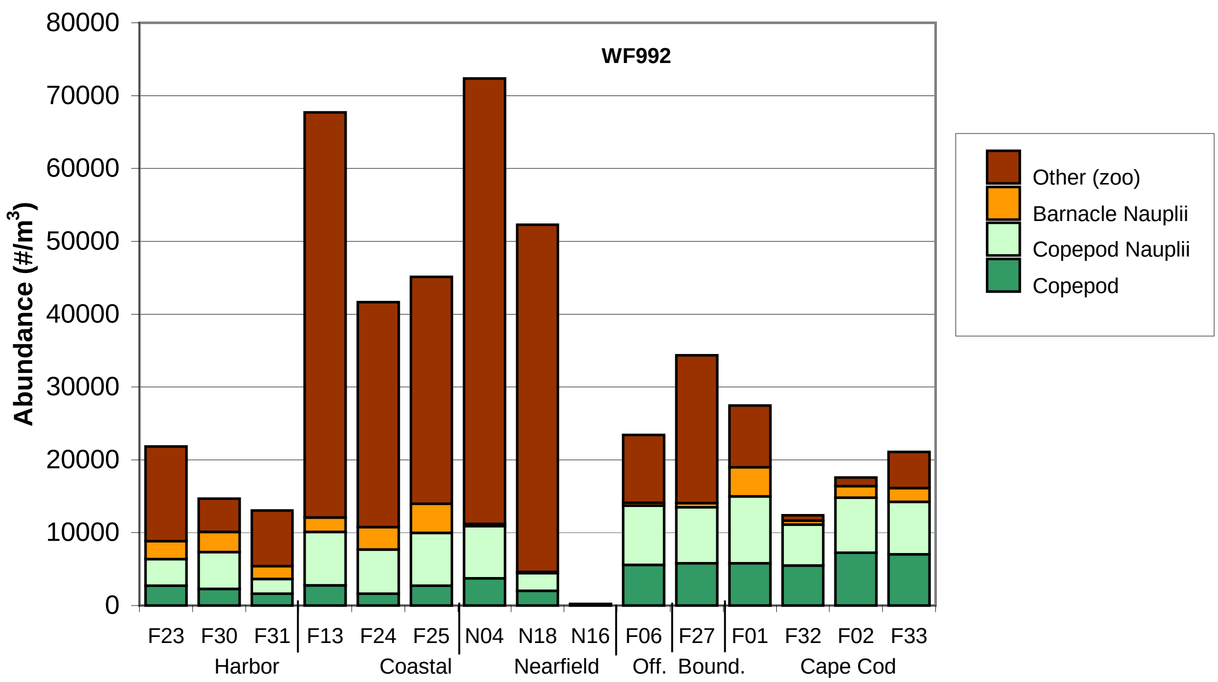


Figure 5-18. Zooplankton Abundance by Major Taxonomic Group – WF992 Farfield Survey Results February 23 – 28, 1999

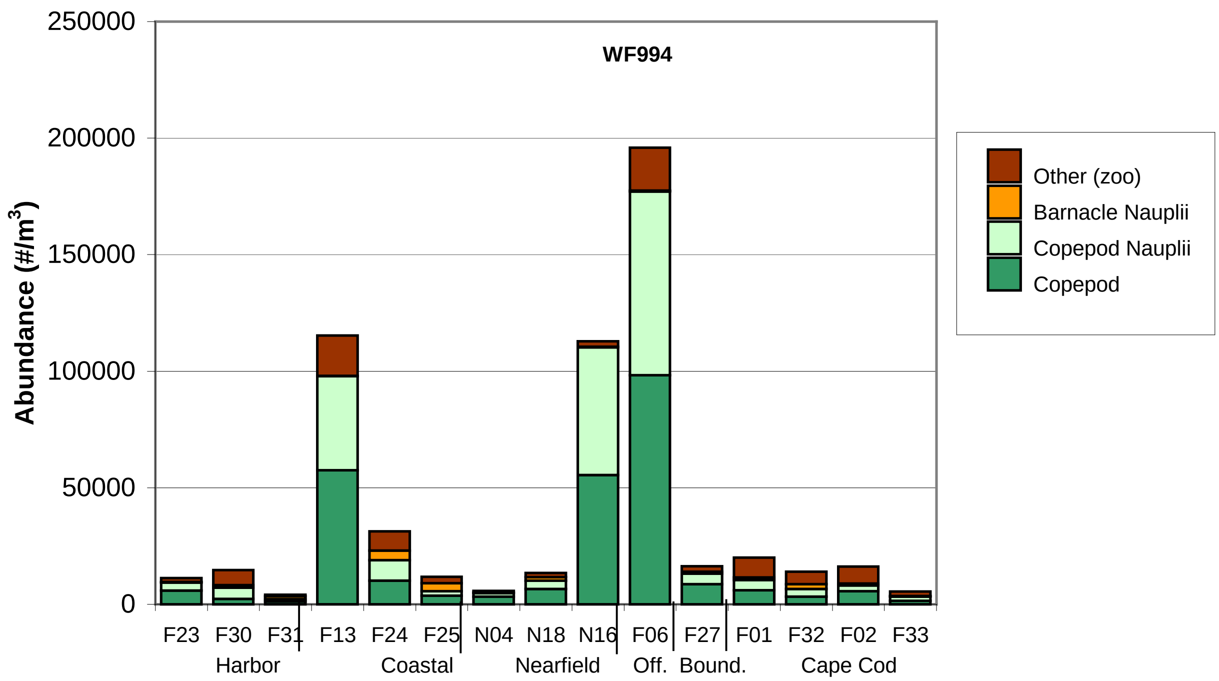


Figure 5-19. Zooplankton Abundance by Major Taxonomic Group – WF994 Farfield Survey Results April 1 – May 6, 1999

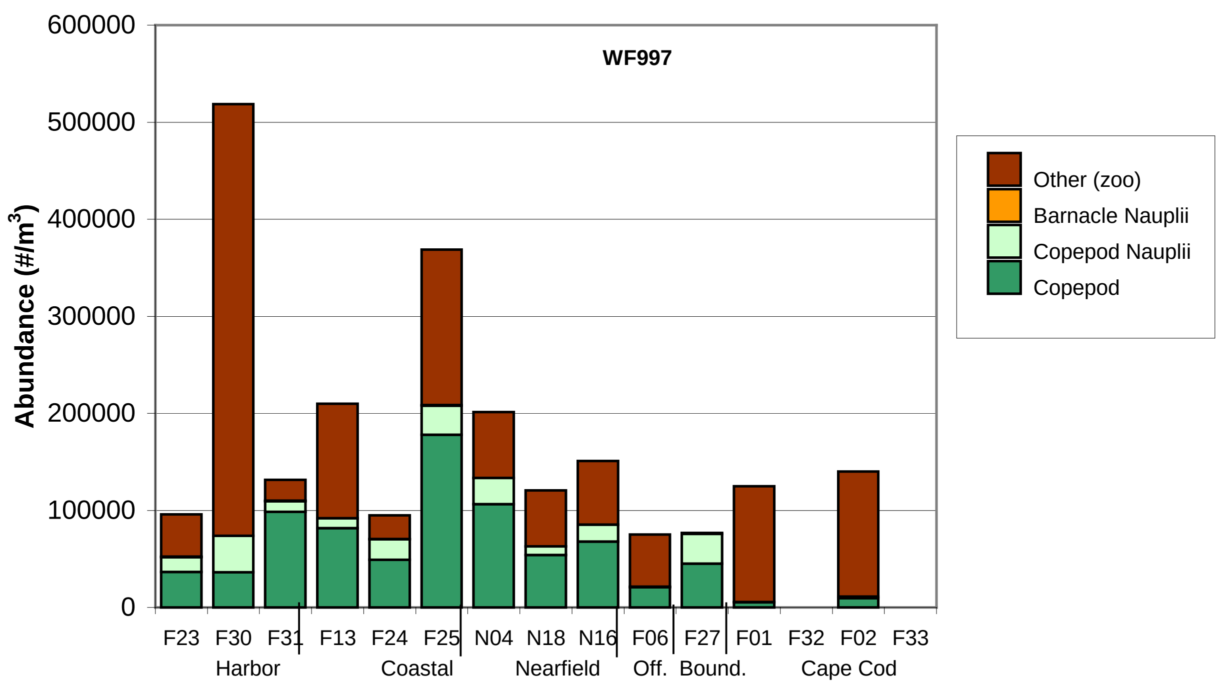


Figure 5-20. Zooplankton Abundance by Major Taxonomic Group – WF997 Farfield Survey Results June 14 – 19, 1999

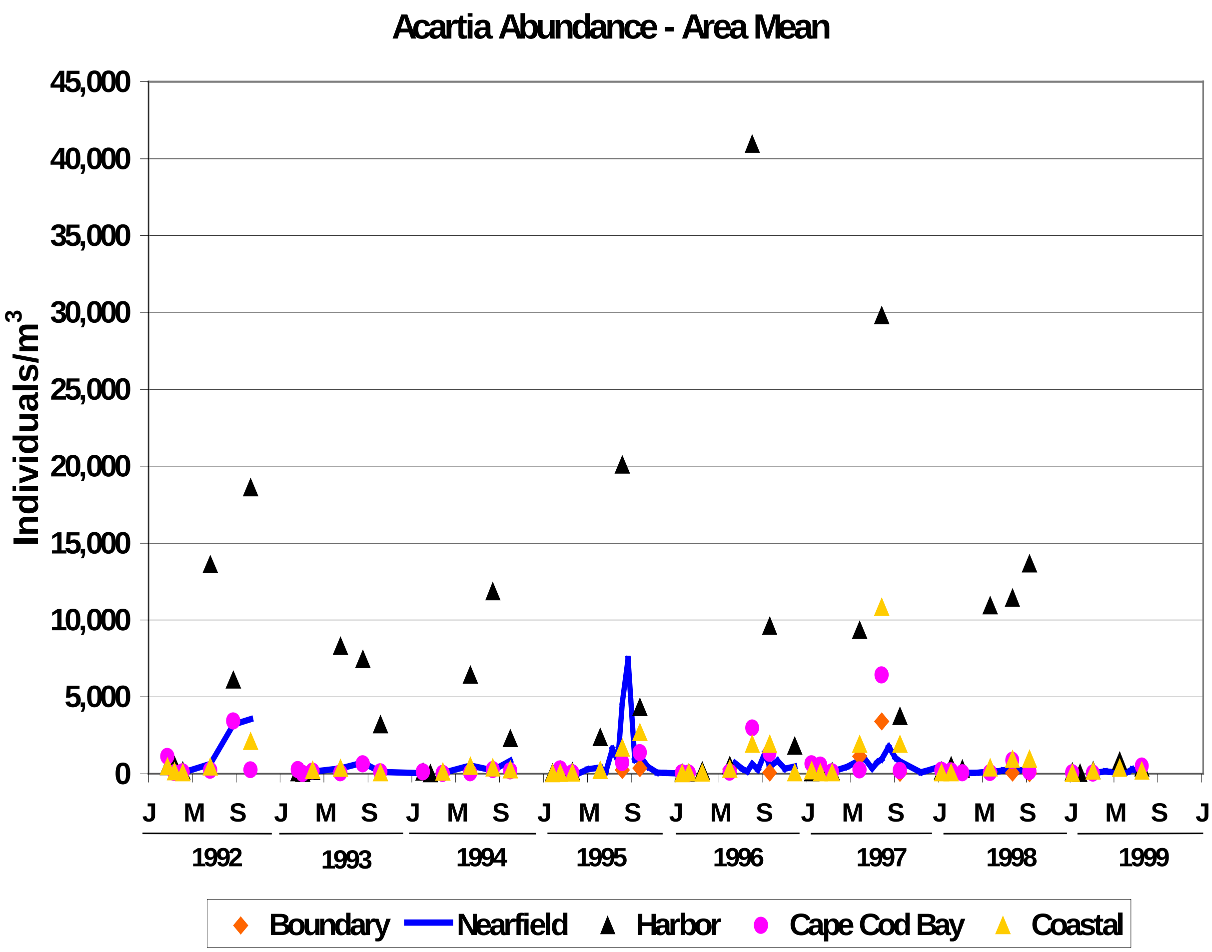


Figure 5—21. Average Acartia Abundance in the Farfield 1992 through 1999

6.0 SUMMARY OF MAJOR WATER COLUMN EVENTS

The winter to spring transition in Massachusetts and Cape Cod Bays is characterized by a typical series of physical, biological, and chemical events: seasonal stratification, the winter/spring phytoplankton bloom, and nutrient depletion. This was generally the case in 1999 with the onset of stratification in April, very high chlorophyll concentrations during the winter/spring period and surface waters depleted in nutrients from May through July. The winter/spring bloom characterized by high chlorophyll concentrations and elevated production rates was not fully represented by the phytoplankton data, which were relatively low in comparison to previous baseline years. This section presents a summary of these events and the integrated physical, biological, and chemical trends discussed in previous sections.

The first three surveys of 1999 (February through March) were conducted prior to the onset of stratification. The water column was well mixed and relatively high concentrations of nutrients were measured. Nutrient concentrations generally decreased from February to March coincident with increasing chlorophyll concentrations and elevated primary production rates. The high nearfield chlorophyll concentrations observed during the winter of 1998 had remained elevated into the winter/spring period of 1999. The phytoplankton community was a mixed assemblage dominated by microflagellates and chain forming centric diatoms (*Chaetoceros* spp.). The pennate diatom, *Pseudo-nitzschia pungens*, which includes both non-toxic *P. pungens* and domoic-acid-producing *P. multiseries*, was observed throughout Massachusetts Bay in early February.

The onset of stratification was observed during the April combined survey. At the deeper nearfield, offshore and boundary stations, the water column had begun to stratify while closer to shore the shallow Harbor, coastal and Cape Cod Bay stations remained well mixed. The onset of stratification in the spring is usually related to a freshening of the surface waters and then as the surface temperatures increase the density gradient or degree of stratification increases. Such was the case in the spring of 1999 as the freshening of the surface layer was coincident with the decrease in surface density and the onset of stratification at the offshore stations. By June the temperature gradient between surface and bottom waters was driving the density gradient that was observed throughout the Bays.

Due to the month long duration of the April combined survey, the data were evaluated over a wide spatial and temporal scale and unusual patterns were observed. The pattern in nutrient concentrations, when evaluated based on sample collection date, revealed that April was a period of increasing biological production and utilization of nutrients. In early April, nutrient concentrations at the boundary and northern offshore area stations were relatively high and comparable to the values observed in late February. By mid-April and early May, nutrient concentrations had decreased to low levels in the nearfield and southern offshore area stations. The winter/spring bloom reduced nutrient concentrations in the surface waters from February to April and with the onset of stratification nutrient concentrations in the surface waters were depleted throughout much of the region by late April/early May.

The high chlorophyll concentrations observed throughout the Bays during the first three surveys continued to be present in April and reached maxima during this survey in the nearfield and offshore areas. The high chlorophyll concentrations in the nearfield during the winter/spring period of 1999 were a continuation of the elevated concentrations observed in late 1998. The mean chlorophyll concentration (5.08 μgL^{-1}) for winter/spring of 1999 was greater than any previous winter/spring mean obtained for the nearfield during the baseline-monitoring period. It also exceeded the chlorophyll threshold value (4.76 μgL^{-1}) that had been calculated as the 95th percentile of the baseline winter/spring distribution for 1992 to 1998. Primary production at the nearfield stations was relatively high during the winter/spring of 1999 reaching values of >2000 mg C m^{-2} d^{-1}, which is comparable to previous winter/spring blooms. Although the nearfield winter/spring chlorophyll concentrations were unprecedented for the baseline-monitoring program, phytoplankton abundance was generally lower than previous winter/spring periods. This may have been because the abundant taxa were large cells (*Ceratium* spp.) and chain forming diatoms (*Chaetoceros* spp.) that may not be adequately captured by bottle sampling or had higher per cell chlorophyll values than dominant species in previous years.

By June, a strong density gradient was observed throughout the Bays except for Boston Harbor stations, which remained well mixed due to tidal flushing. The establishment of seasonal stratification led to nutrient depleted conditions in the surface waters and ultimately to an increase in nutrient concentrations in bottom waters due to increased rates of respiration and remineralization of organic matter. Between the April and June surveys, there was a sharp decline in bottom water DO throughout the Bays of 1-3 mgL^{-1}. The trend of declining bottom water DO concentrations following the establishment of stratification and the cessation of the winter-spring bloom is typical. The large decline that was observed, however, may be an indication that DO utilization may be occurring more rapidly and achieve lower concentration in 1999 compared to previous baseline years.

Chlorophyll concentrations, production rates and total phytoplankton abundance had decreased from the winter/spring bloom highs in Massachusetts and Cape Cod Bays, but the sustained bloom of *Ceratium furca /C. tripos/* C. *longipes* continued through July. In Boston Harbor, chlorophyll concentrations and production rates increased from low values in early February to high values in June. This seasonal pattern is typical for Boston Harbor, which generally exhibits a gradual pattern of increasing areal production from winter through summer rather than the distinct winter-spring peaks observed in the Bays. This was the case in 1999 as production values increased gradually from February through June reaching values of >2500 mg C m^{-2} d^{-1} in April and June.

Total zooplankton abundance also increased from February through June when extraordinary numbers of zooplankton were observed in the nearfield and Boston Harbor. An astonishing maximum value of >500 x 10^3 animals m^{-3} in Boston Harbor was the highest zooplankton abundance recorded for the entire 1992-1999 baseline. Zooplankton assemblages during the first half of 1999 were comprised of typical taxa, but levels of *Acartia* spp. were unusually low, possibly due to drought, and contributions of meroplankton such as bivalve and gastropod veligers and polychaete larvae were unusually high.

A number of topics were called out in this report that will be discussed in greater detail in the 1999 annual water column report including the following:

- Continued observation of high chlorophyll concentrations from late 1998 through winter/spring of 1999 – regional and local trends in chlorophyll and nutrients with additional data from Boston Harbor Monitoring Program and satellite imagery.
- 1999 winter/spring bloom observed in chlorophyll and production data, but not clearly characterized by phytoplankton abundance – regional trends in chlorophyll, production and phytoplankton with additional data from video plankton recorder survey and evaluation of species composition of phytoplankton assemblages during winter/spring (and fall) blooms for entire baseline period.
- Effect of drought conditions in New England region on physical and biological processes in Massachusetts Bay – interannual trends in salinity especially in the Harbor and coastal waters and the biological ramifications of changes in salinity (i.e. *Acartia* abundance)

LIST OF APPENDICES

[Note: These appendices are not available on-line. To obtain a printed copy, please call the Environmental Quality Department at (617) 788-4700.]

7.0 REFERENCES

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